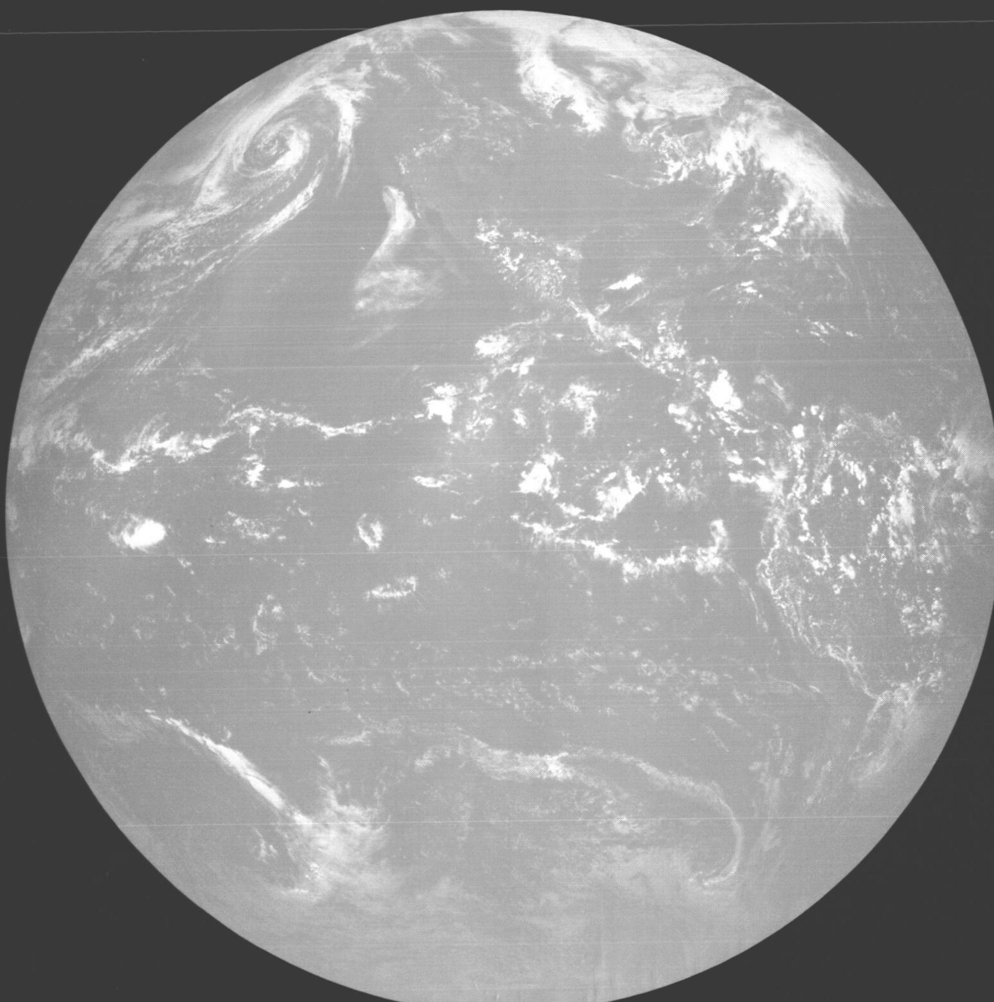
Aeronautics and Space Report of the President



Fiscal Year 1999 Activities

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National Aeronautics and Space Administration

Washington, D.C. 20546

The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 1998, through September 30, 1999.

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National Aeronautics and Space Administration

NASA

In FY 1999, NASA embraced safety as its number one core value, articulating an unwavering commitment to safety for the public, astronauts and pilots, the NASA workforce, and high-value equipment and property. Each NASA Center conducted a safety self-assessment and developed corrective action plans to improve its safety and health programs. NASA safety and mission assurance experts conducted several independent assessments of key NASA systems, including United Space Alliance's Ground Operations, the X-33 and X-34 programs, and the expendable launch vehicle Safety and Mission Assurance (SMA) process, to ensure safe and successful missions. NASA introduced new tools for assessing safety and risk, including the first human factors–based failure modes and effect analysis of critical launch preparation operations. NASA expanded its Probabilistic Risk Assessment (PRA) activity to include a PRA of the International Space Station (ISS) and upgraded the Incident Reporting Information System and the Lessons Learned Information System to better equip NASA's workforce for the prevention of future mishaps and failures.

NASA convinced the International Organization for Standardization's (ISO) SC14 program management standards development working group to incorporate NASA's risk management approach into its

standard, achieving the emphasis on safety that is necessary in international partnerships. In FY 1999, NASA became the first government agency in the world with multiple sites to have every one of its sites under an ISO 9001 registration. NASA's Johnson Space Center became the second U.S. Government installation to achieve "Star" certification under the Occupational Safety and Health Administration's Voluntary Protection Program. (Last year, NASA's Langley Research Center was the first installation to achieve this recognition.)

A number of important human space flight missions marked FY 1999. Each mission was safe; each accomplished the mission objectives; and each was historically significant. The year began with the return to space of John Glenn, the first American to orbit Earth. Senator Glenn flew as a Payload Specialist on Space Shuttle mission STS-95. The primary objective of the flight was to conduct a wide array of research and technology development experiments in a microgravity environment. At age 77, Senator Glenn is the oldest human to fly into space. His participation in this mission provided observational information regarding the links between the effects of space flight and the aging process. Ten of the 83 experiments and payloads on the Shuttle investigated questions pertaining to geriatrics in space. STS-95 also carried a Spartan spacecraft, which gathered scientific data on the solar corona and solar winds.

FY 1999 also saw the first deployment by the Shuttle of an element of the ISS. The first U.S.-built element, Unity (Node 1), along with two pressurized mating adapters, was successfully mated with the Russian-built element, Zarya, which had been launched previously on an unpiloted vehicle. During the year, a second Shuttle mission was flown to the ISS carrying a large amount of supplies and equipment needed to outfit the Station. This marked the first docking of the Shuttle with the ISS.

Another major milestone for the Space Shuttle program was the launch of the Chandra X-ray Observatory. This is the world's most powerful x-ray telescope, and it is the third in NASA's family of "Great Observatories." Because the atmosphere absorbs x-rays, this orbiting spacecraft will enable scientists to study the origin, structure, and evolution of

the universe in greater detail than ever before. The Chandra mission was also flown under NASA's first woman commander, Eileen Collins.

The first two ISS elements were successfully launched and mated during the first quarter of FY 1999. The Zarya control module, or Functional Cargo Block (FGB), was launched on November 20, 1998, by a Russian Proton rocket from the Baikonur Cosmodrome in Kazakhstan. The FGB is essentially an unpiloted space "tugboat" that provides early propulsion, power, and control capability and communications for the Station's first months in orbit. During later assembly, it will provide rendezvous and docking capability to the Service Module. Russia built the FGB under contract to the United States, which owns this element. The Unity connecting module, or Node 1, was launched from the Kennedy Space Center on December 4, 1998, aboard the Space Shuttle *Endeavour*. This was the first of 37 planned Space Shuttle flights to assemble the Station. Unity is a six-sided connector for future Station components. On December 6, 1998, *Endeavour*'s crew rendezvoused with Zarya, and, using a Pressurized Mating Adapter (PMA)-1, attached Unity and Zarya together. PMA-2 provides a Shuttle docking location. Eventually, Unity's six ports will provide connecting points for the Z1 truss exterior framework, the U.S. Laboratory, the airlock, the cupola, Node 3, and the Multi-Purpose Logistics Modules (MPLM). The crew completed connecting the two elements during three subsequent spacewalks, and they also entered the interior of the fledgling ISS to install communications equipment and complete other assembly work. At the end of FY 1999, the two elements were operating nominally in an orbit approximately 250 miles above Earth, with some maintenance required. The Mission Control Center was ready with all the software and hardware needed to support flight 2A in the first quarter of FY 1999. At the fiscal year's end, the Station had completed more than 5,000 orbits.

The Shuttle *Discovery* was launched on May 27, 1999, and performed the first docking with the ISS on May 29, 1999. This was a logistics flight utilizing a SPACEHAB Double Cargo Module. The crew unloaded almost 2 tons of supplies and equipment for the Station and performed one

spacewalk to install a U.S.-developed spacewalkers' crane, the base of a Russian-developed crane, and other spacewalking tools on the Station's exterior for use by future assembly crews. *Discovery* fired its thrusters to reboost the Station's orbit and then undocked on June 3, 1999.

At the end of the fiscal year, U.S. elements for five of the next six assembly flights had been delivered to Kennedy Space Center (KSC) for launch preparation, including truss segments, the attitude control system, the communications system, the first solar array, thermal radiators, integrated electronics, and the U.S. Laboratory ("Destiny"). As hardware continued to flow into KSC, activities focused on acceptance testing, integrated element checkout, and flight software verification. Hardware development activities are declining, as the program enters into the assembly and operations phase. Over 83 percent of the U.S. ISS development contract was completed, with the majority of the U.S. flight hardware scheduled to be delivered to the launch site in 2000.

Relative to international participation, two of the three Italian MPLM's and the Canadian Space Station Remote Manipulator System (SSRMS) were also at KSC in preparation for launch. The Service Module, Zvezda, the first wholly owned Russian ISS element, is currently at the Baikonur launch site undergoing final testing and checkout for an FY 2000 launch.

Also at fiscal year's end, the Japanese Experimental Module (JEM), consisting of a Pressurized Module, Exposed Facility, Remote Manipulator System, and Experiment Logistics Module, was on schedule for launch in the 2003 timeframe. The European Columbus Orbital Facility was in production and on schedule for delivery in early 2004.

Space Station Control Center (SSCC) activities included the completion of the Moscow support room in preparation for the launch of the FGB in early FY 1999. Interface testing between the Mission Control Center–Houston (MCC-H) and the Mission Control Center–Moscow (MCC-M) was complete in late FY 1999, and flight 2A end-to-end testing with KSC was completed successfully in early FY 1999. MCC-H and the flight control team supported flight 2A (December 1998)

and flight 2A.1 (May 1999). MCC-H/MCC-M interface testing was completed in September 1999. The Space Station Training Facility (SSTF) was ready for Expedition 1 training also in September 1999. Other major accomplishments for the SSTF included the delivery of training software for upcoming flights. Assembly-critical spares for flights through 12A.1 were defined and were being manifested on appropriate Shuttle flights.

The development of ISS facility-class payloads made significant progress during FY 1999. Three of five research racks were delivered in preparation for launch on 5A.1, 6A, and 7A.1. The payload planning process was simplified to reduce documentation and risk. The development integration template was revised to reduce product delivery milestones and shorten integration timeframes. Detailed payload manifests were approved for 2000 and 2001.

Contingency planning included near-term plans to augment Russian propulsion and logistics capabilities with the U.S. Shuttle and the preparation of the Interim Control Module (ICM) for launch, needed for reboost and attitude control. Long-term plans included orbiter modifications for additional reboost capability, the development of a permanent U.S. propulsion module, and the provision of six crew return capability with Soyuz until the U.S. Crew Return Vehicle is delivered. In FY 1999, ISS contingency planning activities included the completion of integrated flight configuration tests for an ICM propulsion system, the continuation of work on orbiter fuel transfer modifications, and the initiation of Propulsion Module development. The Propulsion Module System Requirements Review was completed in April 1999, followed by the completion of the Propulsion Module/Shuttle Orbiter Propellant Transfer System Requirements Review in June 1999.

NASA's space, deep space, and ground networks successfully supported all NASA flight missions and numerous commercial, foreign, and other Government agency missions. Included were the first U.S. launch of ISS hardware (the Unity Node), NASA's third Great Observatory (the Chandra X-ray Observatory), Mars Polar Lander, Stardust, Cassini Venus and Earth encounters, and Galilean Moon encounters. The networks provided data delivery for all customers in excess of 98 percent.

Other significant activities included the transition to a Consolidated Space Operations Contract (CSOC), the initiation of Deep Space Network (DSN) service upgrade to Ka-band capability, the completion of DSN 26-meter automation, the initiation of a Mars communications infrastructure phase A study, the completion of an upgrade to the Space Network Control Center, the negotiated coprimary status for a unified S-band spectrum, and the initial acquisition of commercial ground network services.

The CSOC phase-in was completed from October to December 1998, with the transition of nine legacy contracts at Goddard Space Flight Center, Johnson Space Center, Marshall Space Flight Center, Kennedy Space Center, and the Jet Propulsion Laboratory on schedule with no significant problems. At fiscal year's end, cost performance was on track, customer operations were meeting proficiency targets, and workforce reductions were being effected, consistent with the plan. This contract was expected to save taxpayers approximately $1.4 billion over 10 years.

In terms of robotic space flights, there were 32 successful U.S. expendable launch vehicle launches in FY 1999. Of those, 10 were NASA-managed missions; 1 of these was a NASA-funded/Federal Aviation Administration (FAA)-licensed mission, 6 were Department of Defense (DoD)-managed missions (1 of these was a DoD-funded/FAA-licensed mission), and 16 were FAA-licensed commercial successful launches. In addition, NASA flew one payload as a secondary payload on one of the DoD-managed launches. There were four launch vehicle failures—two U.S. Air Force-managed Titan IV's, a commercially licensed Athena II, and a commercially licensed Delta III. NASA participated in the DoD's National Reconnaissance Office (NRO)-led Broad Area Review that included the review of these failures. NASA also participated in the Office of Science and Technology Policy (OSTP)/National Security Council (NSC)-led Interagency Study on Future Management and Use of the U.S. Launch Bases and Ranges.

The Aero-Space Technology Enterprise produced many exciting accomplishments in support of its goals and objectives in FY 1999. These

accomplishments will directly benefit the American people through safer, more affordable, and more environmentally friendly air travel and more efficient and affordable access to space. The Enterprise continued to organize its work according to three "pillars," with associated goals.

Within the first pillar of global civil aviation, the Office of Aero-Space Technology undertook a number of initiatives to increase aviation safety and reduce its environmental impact. As part of the Airframe Systems Program, researchers identified several underlying causes of controlled flight into terrain. NASA also awarded 13 2- to 3-year contracts to develop and demonstrate approaches for fully operational and certifiable synthetic vision and health management systems. Researchers also continued their work on crew-centered synthetic vision display systems.

Under the Aviation Operations Systems Program, Glenn Research Center completed flight tests for the 1998–99 winter icing season with high-fidelity icing cloud instrumentation mounted underside its wing. In combination with instrumentation comparison testing from Glenn's Icing Research Tunnel, conducted in November 1998, this data base provided new knowledge of ice formation processes. NASA cooperated with Atmospheric Environmental Services of Canada and the FAA to analyze such icing data and thus improve safety.

As part of the Advanced Subsonic Technology (AST) Program, researchers demonstrated a low-emission combustor on a Pratt & Whitney 4000 development engine. Results included reductions in oxides of nitrogen (NO_x) levels during the landing and takeoff cycle, reductions in carbon monoxide and unburned hydrocarbon levels, and comparable reductions in cruise NO_x emissions.

In terms of aircraft noise reduction, the AST Program's Aircraft Noise Impact Model combined airport noise prediction, census data, and satellite imagery into a Geographic Information System. The model optimized ground tracks and trajectories for minimized impact and validated the need for improvement at long range.

In the area of weather prediction and adaptation, NASA researchers continued their work on the Advanced Vortex Sensing System (AVOSS).

New features included improved wake prediction (decay and ground effect), improved wake sensor-tracking algorithms and sensor-derived wake residence time in corridor, improvements to the observational weather system, and Weather Nowcast for several hours' forecast of runway throughput. During the fiscal year, an experimental version of AVOSS became operational at Langley Research Center, with live data feeds from the Dallas-Fort Worth airport.

Under pillar two, revolutionary technology leaps, NASA scientists and engineers continued their efforts on the High Speed Research program. They developed a new complete vehicle system design concept that reflected the impacts of the program technology validation efforts and updated technology projections. The technology configuration met or exceeded all of the original program goals—most notably, the takeoff noise goal, which was met, despite a significant increase in stringency over the duration of the program.

Although slowed by technical problems, progress continued during FY 1999 in NASA's cooperative efforts with industry to develop advanced engine technology for general aviation aircraft. Researchers completed assembly as well as initial performance and operability testing on both the advanced internal combustion engine and the small gas turbine engine. They also completed design modifications to correct problems uncovered during the ground-based tests. Researchers remained confident that they could demonstrate both the internal combustion and the turbine engines on experimental aircraft at the Summer 2000 Oshkosh Fly-In in Wisconsin.

Under the AST Program, NASA officials selected final systems for future integration into an Advanced General Aviation Technology Experiment (AGATE) aircraft. The prototype systems included an AGATE Intuitive Pilot Interface and improved structural materials. Researchers continued to develop the Intuitive Pilot Interface (the "Highway in the Sky"), in concert with a multifunctional display, to provide pilots with a graphic depiction of a desired flight path, taking into account weather, traffic, terrain, and any airspace issues without the use of voice communications.

In July 1999, the Environmental Research Aircraft and Sensor Technology (ERAST) project within the Flight Research Program conducted a Remotely Piloted Aircraft (RPA) flight demonstration of an Altus vehicle at Edwards Air Force Base. The purpose of the demonstration was to validate RPA technology for use in science missions of greater than 4 hours in areas such as the polar regions above 55,000 feet. The flight demonstration was a success and further increased design confidence in the application of RPA's as science measurement platforms.

The Flight Research Program also completed the first low-altitude flight of a Helios prototype in September 1999. The flight demonstration included a battery-powered, remotely piloted vehicle aircraft with a wingspan greater than 245 feet suitable for flight to 100,000 feet in altitude or a duration of 100 hours once outfitted with high-performance solar cells.

Under pillar three, access to space, testing of the first development aerospike engine for the X-33 began during FY 1999 at Stennis Space Center. Although slowed by hardware delivery problems and the resolution of environmental concerns at the White Sands Test Facility, progress toward the first flight of the X-34 continued during FY 1999. Stennis Space Center employees conducted hot-fire testing of the Fastrac engine, while other researchers continued building the first powered flight vehicle (A-2).

As a major step in the development of next-generation space transportation propulsion systems, researchers ground-tested a pair of hydrogen-fueled rocket-based combined cycle flowpath models. The flowpath models were tested in all expected operating modes, and the transition from air-augmented rocket to ramjet operating mode has been demonstrated in a new, unique facility that allows for the continuous variation of the simulated Mach number.

The Advanced Space Transportation Program held a Critical Design Review of the Propulsive Small Expendable Deployer System experiment in early September 1999 to review the maturity of the system design. The experiment was scheduled for launch in August 2000, and it is intended to demonstrate the use of electrodynamic tethers as a means of propulsion in space without the use of propellants.

While there were both ups and downs for NASA's Space Science Enterprise this year, overall, there was a wealth of dramatic science delivered in all four of its science theme areas. In addition to the thousands of breathtaking images that the Hubble Space Telescope continued to deliver, one result was a long-awaited, scientific coup: after 8 years of painstaking measurements, Hubble scientists calculated a value for how fast the universe is expanding. The rate of expansion, called the Hubble constant, is essential to determining the age and size of the universe, which scientists have now determined to be approximately 12 billion years old. Measuring the Hubble constant was one of the three major goals for the telescope when it was launched in 1990.

In planetary news, the Mars Global Surveyor spacecraft has given us the first global, three-dimensional map of the Martian surface. This incredible data base means that we now know the topography of Mars better than many continental regions of Earth. This mapping mission has revealed many new insights about the varying topography of Mars, including an impact basin deep enough to swallow Mount Everest, mysterious magnetic lines on the ancient surface reminiscent of plate tectonics on Earth, and weather patterns raging across the Martian north pole. This new global map of Mars is changing our fundamental understanding of the Red Planet and will likely influence scientific research of Mars for years to come. The increasingly detailed high-resolution map represents 250 million elevation measurements gathered in 1998 and 1999.

The Cassini spacecraft, currently on a journey to Saturn, completed a highly accurate swingby of Earth in August. This flyby was necessary to give Cassini a boost in speed, sending it toward a rendezvous with Saturn and its moon Titan in 2004.

Astronomers, racing the clock, managed to take the first-ever optical images of one of the most powerful explosions in the universe—a gamma-ray burst—just as it was occurring on January 23, 1999. Such bursts occur with no warning and typically last for just a few seconds. Later in the year, other astronomers, funded by NASA, witnessed a distant planet passing in front of its star, providing direct and independent confirmation of the exis-

tence of extrasolar planets that to date has been inferred only from the wobble of their star.

In July 1999, the Space Shuttle *Columbia* successfully carried to orbit the Chandra X-ray Observatory, the third of NASA's four Great Observatories, joining the Hubble Space Telescope and the Compton Gamma Ray Observatory. The results to date from Chandra have been dramatic. After barely 2 months in space, Chandra took a stunning image of the Crab Nebula, the most intensively studied object beyond our solar system, and revealed something never seen before: a brilliant ring around the nebula's heart. Its performance and images continue to delight astronomers.

Using the Japanese Yohkoh spacecraft, NASA-sponsored scientists have discovered that an S-shaped structure often appears on our own Sun in advance of a violent eruption, called a coronal mass ejection, which is as powerful as billions of nuclear explosions. Early warnings of approaching solar storms could prove useful to power companies, the satellite communications industry, and organizations that operate spacecraft, including NASA.

The Office of Life and Microgravity Sciences and Applications (OLMSA) released five NASA Research Announcements (NRA) in FY 1999 and built its investigator community to 877 investigations (a 9-percent increase over 1998) as part of continuing preparations for ISS utilization. In addition to regular releases of NRA's, OLMSA also began selecting research in biologically inspired technology through a dedicated NRA. FY 1999 included the flight of STS-95, a Space Shuttle mission to conduct research in the life and microgravity sciences, including some exploratory research on aging and space flight.

Industry investment in commercial space and microgravity research is at an all-time high. NASA flew 10 commercial payloads, consisting of more than 25 commercial investigations, during FY 1999. Industry has reported considerable—and, in some cases, remarkable—success from these cooperative missions. In addition, industry affiliates in the OLMSA Commercial Space Centers (CSC) have again increased, this time to

163 affiliates at fiscal year's end. The leveraging of industry support to the NASA CSC's has risen to five industrial dollars for every NASA dollar spent.

Life and microgravity researchers convened in FY 1999 to conduct a 1-year postflight review of results from the Neurolab Space Shuttle mission. Data from Neurolab flight experiments confirmed and expanded upon previous space flight data that the vestibular system—the system that senses gravity, maintains balance, and helps regulate control of movement—undergoes significant remodeling in response to microgravity. Additional results from Neurolab include the observations that the cells in the cerebral cortex of fetal mice divided more rapidly in space than on Earth, and there was a reduction in size and development of antigravity muscles in young rats exposed to space as compared to those on Earth.

As part of a continuing effort in the application of NASA technologies to telemedicine, a Virtual Collaborative Clinic was held at NASA's Ames Research Center on May 4, 1999. Physicians and technical staff at multiple remote sites interacted in real time with three-dimensional visualizations of patient-specific data using next-generation high-bandwidth networks. The participants were from Cleveland Clinic, NASA's Glenn Research Center, Northern Navajo Medical Service Center in Shiprock, New Mexico; Stanford University, Salinas Valley Memorial Hospital, the University of California at Santa Cruz, and Ames Research Center. Medical visualizations were a stereo reconstruction from a computerized tomography (CT) scan of a heart with a graft, stereo dynamic reconstructions (beating heart) of echocardiograms with Doppler effects, and three-dimensional virtual jaw surgery using NASA's CyberScalpel for irregular-shaped or round bones and organs.

Dr. William Ballhaus, Vice President of Lockheed Martin Corporation, convened an Industrial Liaison Board, formed through an initiative of NASA's National Center for Microgravity Research on Fluids and Combustion. The board made an initial set of recommendations on ways NASA could enhance the value of its research in microgravity fluids and combustion research to the industrial sector.

A special optical detector developed by the Space Vacuum Epitaxy Center, a NASA CSC, may offer the gift of sight to people with a variety of eye problems. The detector is designed to be implanted on the back wall of the eye, replacing natural sensors damaged by disease or accident. The detector converts light into electrical signals in much the same way as rods and cones operate in a healthy eye, and the optical nerve then picks up those signals. Preliminary testing has been successful, and efforts at commercial development began during FY 1999.

The Ford Motor Company has used materials data supplied by the Solidification Design Center, a NASA CSC, to design new, high-quality sand-molding processes for creating precision automotive parts. This type of work is also being done by the Solidification Design Center for Alcoa and Howmet Corporation to cast parts that are more reliable and yet lower in cost.

Two new types of cameras that were developed by the Center for Commercial Applications of Combustion in Space and Roper Scientific for combustion research have been applied to the field of medicine. A double-image camera and a gated integrator camera are being marketed in the multibillion-dollar medical imaging field. This new technology will allow weak images to be pulled from strong backgrounds, such as when tumors have the same general color and lighting as the surrounding tissue.

FY 1999 was a year of substantial scientific accomplishment in our understanding of the major elements that comprise the Earth's system. Over the oceans, the Earth Science Enterprise (ESE) reduced the uncertainty in global rainfall over the tropics (helping improve short-term weather prediction and the availability of fresh water globally), produced near-daily ocean color maps that help us understand the role of oceans in removing carbon dioxide from the atmosphere, documented the waxing and waning of El Niño (enabling seasonal climate prediction), and resumed global measurement of winds at the ocean surface to improve short-term weather prediction and the tracking of major hurricanes and tropical storms globally.

Over the ice caps, researchers determined the thinning and thickening rates for the Greenland ice sheet, provided the first detailed radar mosaic of Antarctica, and provided daily observations of the polar regions from space. Over the land, ESE produced the first satellite-derived assessments of global forest cover, began refreshing the global archive of 30-meter land-cover data, and conducted an international field experiment in the Amazonia to help understand the role of vegetation on Earth in removing carbon dioxide from the atmosphere. In terms of the solid Earth, ESE and the U.S. Geological Survey measured surface displacement, a precursor to earthquakes, in the Los Angeles basin. With respect to the atmosphere, ESE continued to measure concentrations of both ozone and ozone-depleting substances and to assess the recovery of upper ozone correlation. ESE also implemented a 17-year data record of aerosols and cloud properties toward predicting annual-to-decadal climate variations.

ESE continued to fulfill its commitment to make its Earth observation data widely available for research and education. Almost 1,300,000 distinct users obtained 5.2 million data products during the year. ESE sponsored 350 workshops to train more than 11,000 educators in the use of Earth science concepts and teaching tools, and it awarded 50 new fellowships to maintain support annually for 150 graduate students at U.S. universities to train the next generation of Earth scientists.

ESE continued to ensure that its data and associated information and knowledge lead to practical solutions for business and local governments. ESE established 29 partnerships to develop applications of Earth remote-sensing data for agriculture, natural resources management, urban and regional planning, and disaster mitigation. More than 100 commercial partnerships helped a variety of firms use remote-sensing data to develop or improve their products and services. ESE researchers contributed to four national and international scientific assessments of the environment to provide policymakers with an objective basis for decisionmaking.

During FY 1999, ESE successfully launched the Landsat 7 and Quick Scatterometer (QuikSCAT) spacecraft. Landsat 7 builds on the heritage of the Landsat program by contributing to a three-decade-long record of ter-

restrial ecosystems and their change. The QuikSCAT instruments were designed to map wind speed and direction across 90 percent of Earth's ice-free oceans. Scientists planned to use data from QuikSCAT and the Ocean Topography Experiment (TOPEX/Poseidon) to look at the effects of ocean height and wind patterns on the ocean waves and currents. The Terra launch was rescheduled to early FY 2000 because of launch vehicle recertification.

NASA also continued its international outreach, expanding cooperation with its partners through new agreements, discussions in multilateral forums, and support for ongoing missions. NASA concluded more than 50 cooperative and reimbursable international agreements for projects in each of NASA's Strategic Enterprises. These agreements include aeronautics research; the use of aircraft, balloons, and sounding rockets for scientific research campaigns; and the flight of instruments on satellites and the Space Shuttle. The ground-based Aerosol Robotic Network expanded to include 13 additional countries in Africa, the Americas, and Europe. The NASA Administrator and his counterparts signed several significant agreements for cooperation in Latin America in December 1999. An agreement between NASA and the Central American Commission on Environment and Development established cooperation on the development of a Mesoamerican biological corridor. Two agreements with Brazil established cooperation on the project for the Large-Scale Atmosphere-Biosphere Experiment in Amazonia: one for the ecological research component and another for the Tropical Rainfall Measuring Mission (TRMM) component.

NASA played a key role in the UNISPACE III conference held July 19–30, 1999, in Vienna, Austria. This third United Nations world conference on space activities produced a report with information on the status of space activities around the world, issues that need to be addressed, and recommended actions for the future. NASA participated in the preparations for the conference, including the Regional Preparatory Conference for Latin America, held October 12–16, 1998, in Chile, and all of the meetings leading up to and during the conference that reviewed and

approved the report and its "Vienna Declaration." NASA provided support to all aspects of the conference, including governmental meetings, the technical forum, and the exhibit. NASA also continued to support the ongoing activities of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and its subcommittees, particularly on the subject of orbital debris. The Scientific and Technical Subcommittee concluded its multiyear work plan and published a "Technical Report on Space Debris." Through cooperation with NASA, Ørsted and Sunsat, the first satellites for Denmark and South Africa, respectively, were launched as secondary payloads on a Delta vehicle in February 1999.

The NASA Administrator served as the President's Representative to the Paris Air Show, held in June 1999. In addition, the Administrator visited Russia, Spain, Italy, Germany, Norway, and Romania to meet with senior foreign officials concerning ongoing and potential cooperation.

Department of Defense

DoD

During FY 1999, the Interagency GPS Executive Board further refined plans for modernizing the Global Positioning System (GPS) satellite constellation. GPS provides precise position, timing, and velocity information to civil and military users worldwide. As a result of a thorough review of national requirements for public-sector navigation, two new civil navigation frequencies will be phased in over the next decade. A second civil signal at 1,227 megahertz (MHz) will be similar to the existing signal at 1,575 MHz. A third civil signal, designed for 1,176 MHz, will support civil aviation by further enhancing the robustness and accuracy of the GPS. The U.S. delegation to the recently concluded World Radiocommunication Conference 2000 in Istanbul was successful in gaining approval for the third civil frequency and the requisite authorizations for use of all three frequencies in space. These new civil signals will enable the civil community to develop a broad range of new and improved GPS applications.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) is a joint mission involving the Departments of Defense and Commerce and NASA. During FY 1999, the NPOESS program office and NASA developed a strategy for placing selected imaging and sounding systems on orbit several years before the first NPOESS is launched. This effort is known as NPP. The tri-agency NPP team performed NPP spacecraft concept studies, conducted mission architecture concept studies, and drafted the mission's technology demonstration plan. NPP will provide important data to NASA as a bridging mission between NASA's Earth Observing Systems. NPP will also provide technical and schedule risk reduction for new NPOESS sensors, as well as an opportunity for operational users to test the new sensors and their associated flight and data-processing algorithms. In addition, flight-testing NPOESS sensors on NPP

minimizes the test and checkout period of the first operational NPOESS satellite and therefore maximizes the operational utility of the first NPOESS satellite. Additional details on NPOESS progress are covered in the Department of Commerce section of this report.

DoD, NASA, NOAA, and other Federal agencies teamed together to complete a comprehensive Space Weather Architecture study during FY 1999. This study laid out the structure for space weather architecture to meet all U.S. Government requirements and mitigate the adverse impacts of solar events by the year 2025.

In September 1999, DoD officials also approved the Wideband gapfiller to be the first DoD-owned MilSatCom system to be procured under the Federal Acquisition Regulation Part 12, which governs acquisition of commercial items.

During FY 1999, DoD continued to work on the Evolved Expendable Launch Vehicle (EELV) program to develop a national launch capability that satisfies Government requirements and reduces launch costs by at least 25 percent. The Air Force announced the award of contracts valued at a total of $3 billion to Lockheed Martin and Boeing. DoD awarded each of the companies a $500 million contract for engineering and manufacturing development agreements. The two companies also have contracts for initial launch services of DoD's EELV program that total $2.03 billion; Boeing received 19 launches at $1.38 billion, and Lockheed Martin received $650 million for 9 launches. The EELV program's objective is to improve the affordability and operability of the Nation's expendable launch systems and to replace the current fleet of medium and heavy launch systems with two modular families of launch vehicles

During 1998–99, three DoD satellite launches on variants of the Titan IV vehicle and upper stages failed at a total dollar loss in excess of $3 billion. In May 1999, the President requested that the Secretary of Defense, in coordination with the Director of Central Intelligence and the NASA Administrator, examine the failures and to provide a report on the causes and corrective actions being taken to prevent their recurrence and to ensure future access to space. The DoD Assessment of Space Launch Failures Report summarizes the results of independent industry reviews, Air Force accident investigation boards, and an Air Force/National Reconnaissance Office (NRO)–directed Broad Area Review. It concluded that a combination of technical and process deficiencies contributed to the failures. DoD has already taken many actions to correct the specific problems that contributed to the three failures that sparked this intense review, and more steps are under way.

Federal Aviation Administration

FAA

The FAA continued a dynamic research and development program in support of its mission to provide a safe, secure, and efficient global aerospace system that contributes to national security and the promotion of U.S. aerospace safety. During the fiscal year, the agency worked with the aviation industry to update the National Airspace System Plan through 2015. The plan is based on the "Free Flight" operational concept in which pilots may choose the most efficient and economical routes to their destinations. The agency continued to acquire new automation systems for the National Airspace System (NAS), installing the Host and Oceanic Computer System Replacement at its 20 air traffic control centers and three oceanic centers. The system provides information on aircraft movements throughout domestic and oceanic airspace, and it is faster and more reliable than its predecessor system. The agency also deployed the Display System Replacement to eight en route centers, replacing 30-year-old equipment and providing enhanced capability to display aircraft position, identification, and weather information, as well as monitor and control system equipment and support planned enhancements to the air traffic control environment.

The agency achieved a major milestone in its Free Flight Phase 1 program in FY 1999 when the Surface Movement Advisor, which provides aircraft arrival information to airline ramp towers and operation centers,

became available to airlines at Detroit Metropolitan and Philadelphia International Airports. The agency made two major upgrades to its User Request Evaluation Tool (URET) at the Indianapolis and Memphis air route traffic control centers. URET provides controllers with automatic conflict detection, trial planning for assistance with conflict resolution or user requests, conformance monitoring of current flight trajectory, and some electronic flight data capability. The FAA and NASA researchers also continued joint efforts on air traffic management systems that will enhance the capacity and efficiency of the NAS. For example, NASA is working with the FAA to develop some of the necessary tools to implement Free Flight Phase 1, such as the Passive Final Approach Spacing Tool and the Surface Movement Advisor.

The Safe Flight 21 program, a joint Government-industry initiative designed to validate the capabilities of advanced communication, navigation, and surveillance, as well as air traffic procedures associated with free flight, began demonstrating Automatic Dependent Surveillance-Broadcast (ADS-B) technology. In July 1999, 25 aircraft from the Cargo Airline Association, the FAA, avionics manufacturers, universities, the U.S. Navy, and NASA participated in a flight demonstration to begin testing ADS-B. UPS Aviation Technologies, Inc., a subsidiary of United Parcel Service, demonstrated its proposed avionics equipment in Bethel, Alaska. As a result of that test, the FAA awarded a $3.9 million contract to UPS Aviation Technologies for state-of-the-art avionics systems, installation kits, terrain data bases, ground-based transceivers, an avionics training simulator, and training assistance. The FAA continued progress toward implementation of the Wide Area Augmentation System (WAAS) that will provide the availability, integrity, and accuracy for the GPS to be used for en route navigation and precision civilian navigation. During the fiscal year, the agency completed a series of Category 1 precision approach test flights at Iceland's Keflavík airport, using signals from both the FAA's WAAS test bed and the United Kingdom's Northern European Satellite Test Bed. The FAA leased three ground reference stations and a master station to the Chilean government

for flight testing satellite navigation in Chile. The Chilean government outfitted an aircraft with a GPS receiver to fly precision and nonprecision Category 1 instrument flight rules conditions at the Arturo Merino Benitez International Airport in Santiago. With support from the Civil Aviation Authority of Singapore, the FAA also installed and tested a WAAS test reference station at Singapore's Changi Airport.

During the fiscal year, the FAA developed and installed in all FAA, DoD, and National Weather Service NEXRAD weather radars, an advanced algorithm that detects tornadoes early in their development and indicates the direction they will move. On the prototype Integrated Terminal Weather System at the Orlando TRACON, the agency installed a convective growth and decay forecast product, which not only predicts thunderstorm movement, based on the storm's track, but also includes the effects of storm growth and decay.

The FAA transferred to industry its Weather Support to Deicing Decision Making (WSDDM) system, a stand-alone, integrated display system developed in response to industry's need for accurate, local weather data to plan and conduct airport deicing operations, and the agency began using the system at LaGuardia Airport. WSDDM uses Doppler radar, surface weather station data, and snow gauges located at and near the airport to determine precipitation type, temperature, wind speed and direction, and the liquid water equivalent of snow.

The FAA released an upgraded version of the Integrated Noise Model (INM) 6.0. INM is the FAA's standard tool for assessing aircraft noise in the vicinity of airports and is the most widely used model of its kind in the world. The FAA and NASA continued research activities under the Atmospheric Effects of Aviation Project (AEAP). The scientific findings from the AEAP served as a significant input to the *Special Report on Aviation and the Global Atmosphere* published by the Intergovernmental Panel on Climate Change. The report indicates that the growing demand for air transportation services may cause aviation's current small contribution to climate change to increase substantially in the future. Scientific understanding of the effects of carbon dioxide is good, while only fair to

very poor for the effects of other aircraft emissions on ozone and cloudiness. The report is being used as a basis for policy recommendation by the International Civil Aviation Organization. The two agencies also completed research activities under the Advanced Subsonic Technology program to develop combustor technology to reduce aircraft engine exhaust emissions.

During the fiscal year, the FAA and NASA expanded integrated efforts to reduce the fatal commercial accident rate by 80 percent by 2026. Researchers are working together to better understand and develop technologies to mitigate the effects of phenomena such as wind shear and in-flight icing and to prevent accidents by finding the means to detect potential structural problems in the Nation's aging airline fleet. As part of its safety efforts, the FAA continued advanced research activities in a number of critical aviation safety areas. Researchers developed new stringent fire test criteria for aircraft thermal acoustical insulation aimed at preventing in-flight fires originating in hidden areas of the aircraft. The Aging Non-Structural Systems Research Program formally got under way in FY 1999 to develop a test and validation infrastructure, develop wire testing equipment, assess visual inspection, and develop aircraft arc fault circuit breakers. The agency completed the construction of the Full-Scale Aircraft Structural Test Evaluation and Research facility, which is being used to test fuselage panel specimens under conditions representative of those seen by an aircraft in actual operation.

In addition, the agency released a software code called Design Assessment of Reliability With Inspection (DARWIN) that will improve the structural integrity of turbine engine rotor disks used in commercial aircraft engines by assessing rotor design and life management. The FAA and the Helicopter Association International developed and released a Web-based Maintenance Malfunction Information Reporting system, which allows helicopter operators and repair stations to fulfill FAA Service Difficulty Reporting requirements and create manufacturer warranty claim forms. Researchers at the FAA's Airworthiness Assurance Center of Excellence completed a first-generation PC version of XRSIM, which sim-

ulates radiographic (x-ray) inspection of aircraft components and is used during the development of inspection procedures to optimize radiographic inspections. The agency also developed the Web-based Air Personnel Module of Safety Performance Analysis System, which expedites the Aviation Safety Inspector's activities in the areas of certification, recertification, surveillance, and investigation by providing readily accessible information from a variety of data sources and highlighting important information. The agency also certified AlliedSignal TCAS II Version 7, incorporating more than 300 detailed modifications to the surveillance and collision avoidance algorithms and displays in TCAS II avionics equipment.

To learn more about the occurrences and characteristics of freezing drizzle aloft, FAA researchers continued to develop a centralized data base of fine-scale measurements in these kinds of icing conditions. The agency also sponsored the development of a prototype aircraft-mounted wide area ice detection system, which is now installed in the FAA Technical Center's B-727 ground test vehicle for preliminary tests.

In May 1999, an American Eagle commuter aircraft landed long on runway 4R at John F. Kennedy International Airport and stopped 250 feet into a cellular cement arrestor bed, a passive aircraft arrestor system developed and tested by the FAA, the Port Authority of New York and New Jersey, and Engineered Systems Company. All 30 people on board escaped injury, and the aircraft experienced only minor damage. In April, the FAA dedicated its new National Airport Pavement Test Facility, designed to provide high-quality, accelerated test data from rigid and flexible pavements subjected to simulated aircraft traffic. In September, the FAA conducted with Boeing the first set of full-scale pavement tests at the facility.

In FY 1999, the FAA developed and initiated an extensive research and development program in the area of wildlife strike mitigation and completed a wildlife control manual, which offers practical solutions to problems of habitat modification and wildlife management. The agency, in conjunction with the Port Authority of New York and New Jersey, completed a study investigating the effect of tall grass on bird activity at John

F. Kennedy International Airport, and it continued to expand the National Wildlife Strike Database, which lists and details wildlife strike reports.

Human factors research continued to increase the safety and efficiency of the NAS by developing guidance for improving the performance of air carrier crews, general aviation pilots, aviation maintenance personnel, air traffic controllers, and NAS system maintenance technicians. Aviation medicine research proceeded with efforts to improve the health, safety, and survivability of aircraft passengers through the development of recommendations for counteracting human failure conditions. During the fiscal year, human factors practitioners researched a new training development methodology that allows air carriers to present unique training and assessment experiences for each flight crew, greatly enhancing training and assessment capabilities and benefits. The FAA, in collaboration with NASA, produced a manual for developing operating documents that provide guidelines on the organization and design of checklists, quick reference handbooks, and guides used on the flight deck. Researchers also developed guidelines on maintenance resource and error management. The human factors research program completed a human-in-the-loop high-fidelity simulation to investigate controller performance and workload impacts resulting from airspace boundary adjustments. Research began on a congressionally directed survey focused on the effects of shiftwork scheduling practices and fatigue in the air traffic system workforce. The human factors program continued to support the National Institute for Occupational Safety and Health Cabin Air Quality Study ordered by Congress. In addition, researchers developed an analytical technique that employs DNA probes to differentiate blood alcohol intake before death from alcohol produced by the body through natural processes after death. This will prevent incorrect conclusions from accident investigations.

The FAA continued its research and development activities to prevent explosives, weapons, and other threat materials from being introduced onto aircraft. To detect weapons in checked luggage, the FAA worked with industry to certify two new explosives detection systems, the L3 eXaminer 3DX6000 and the InVision CTX9000. Agency researchers synthesized and

characterized a new terrorist explosive, triacetone triperoxide (TATP), which recently appeared as a weapon of mass destruction in the Middle East, and adapted the current generation of explosives trace detection systems to detect TATP. The agency also established an explosives standard system (Trace Personnel Standard—Dry Transfer Method), enabling the evaluation of emerging explosives trace detection technology. In addition, the FAA completed the screener selection test assessment and fielded six perceptual and cognitive tests at 18 major U.S. airports to develop a screener aptitude test to predict future performance of checkpoint security screener candidates. The FAA provided more than 250 copies of the Blast/FX software tool to Government agencies. Blast/FX is a self-contained software package that can be used to model and analyze the effects of a blast on facilities (see the Web site: *www.blastfx.com*). The agency also conducted two Radio Frequency Identification (RFID) Baggage Tag trials, in conjunction with United and Continental Airlines. The tests provided critical operational performance information to support airline efforts to develop an international standard for RFID Baggage Tag use.

The FAA's Office of Commercial Space Transportation licensed two successful launches by sea launch during the fiscal year. These were the first licensed launches without any involvement from a Federal launch range. Overall, there were 18 launches during the fiscal year that were FAA licensed as commercial, although 2 were failures. The agency also issued a launch operator license to Orbital Sciences Corporation for the first commercial launches from Kwajalein Missile Range, operated by the U.S. Army, in the Marshall Islands, Pacific Ocean, and renewed five launch operator licenses. The FAA and NASA signed a Memorandum of Understanding Concerning Future Space Transportation Systems, which describes the FAA/NASA cooperative activities that will be conducted under the category of future space transportation systems and Reusable Launch Vehicle (RLV) technology, research, and development. The agency and its Commercial Space Transportation Advisory Committee released the 1999 Commercial Space Transportation Forecasts, which project an average total of 51 commercial space launches per year through 2010, an

increase of over 40 percent from the 36 commercial launches conducted worldwide in 1998.

The agency issued final rules on Financial Responsibility Requirements for Licensed Launch Activities and Commercial Transportation Licensing Regulation. It also issued notices of proposed rulemaking on Commercial Space Transportation Reusable Launch Vehicle and Reentry Licensing Regulation, Licensing and Safety Requirements for Operation of a Launch Site, and Financial Responsibility Requirements for Licensed Reentry Activities. In addition, the FAA published a Draft Programmatic Environmental Impact Statement for Commercial Launch Vehicle Programs as part of its responsibility under the National Environmental Policy Act.

DEPARTMENT OF COMMERCE

DoC

In FY 1999, the DoC engaged in a wide variety of activities that furthered U.S. interests in aeronautics and space, including satellite operations and licensing, technology development, civilian and commercial space policy support, trade promotion, and patent approval. The National Oceanic and Atmospheric Administration (NOAA) engaged in a number of space activities during FY 1999. Within the National Environmental Satellite, Data and Information Service (NESDIS), Gregory W. Withee was named Assistant Administrator for Satellite and Information Services in May 1999. NESDIS operates the U.S. civil geostationary and polar-orbiting weather satellites, maintains environmental data used by scientists throughout the world, and licenses the commercial remote-sensing industry.

NOAA's polar satellites—NOAA-14 and NOAA-15, launched in December 1994 and May 1998, respectively—continued to monitor the entire Earth, tracking atmospheric variables and providing atmospheric data and cloud images. These satellites continued to send more than 16,000 global measurements daily via NOAA's command and data acquisition stations and provide valuable information for forecasting models, especially for remote ocean areas for which conventional surface observations are lacking.

In May 1999, a $91 million contract was awarded to Ball Aerospace Technologies to develop a suite of satellite instruments that will significantly improve the accuracy of Earth's ozone measurements. The contract, for the design and fabrication of the Ozone Mapping and Profiler Suite (OMPS), is to produce three OMPS units that will be flown as part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program.

ITT Industries was awarded a $98 million contract in August 1999 to develop an advanced weather satellite instrument that will significantly improve weather forecasting and climate prediction. The contract is for a Cross-track Infrared Sounder (CrIS), an advanced high-spectral-resolution infrared sounder to be flown aboard the U.S. environmental satellites of the future as part of the NPOESS. The first CrIS unit is to be flown on the NPOESS Preparatory Project mission, beginning in late 2005, to test and evaluate CrIS prior to the launch of the first operational NPOESS spacecraft in 2008.

These developments in the NPOESS program, as well as the transfer of satellite operations for the Defense Meteorological Satellite Program (DMSP) to NOAA's Suitland, Maryland, facility, represented a major step forward in the merger of U.S. civilian and military operational environmental satellites into a single, national system. Once operational in the next decade, the NPOESS will satisfy both civil and national security requirements for space-based, remotely sensed environmental data.

Two Geostationary Operational Environmental Satellites (GOES)—GOES-8 or GOES-East, stationed at 75 degrees west longitude (launched in April 1994), and GOES-10 or GOES-West, at 135 degrees west longitude (launched in April 1997)—continued to provide the kind of continuous monitoring necessary for intensive data analysis during severe weather conditions. These satellites transmit full-disc views of the majority of the Western Hemisphere that provide a constant vigil for the atmospheric "triggers" for severe weather conditions, such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop, the GOES satellites are able to monitor storm development and track the

storms' movements. In addition to satellite operations, NOAA continued to provide space weather monitoring and forecasts to protect spacecraft and power grids during the current solar maximum expected to peak in 2000.

The launch of GOES-L, originally planned for May 1999, was delayed to allow NASA, NOAA, and rocket manufacturers time to review recent launch failures. Successfully launched in May 2000, GOES-L will be stored onorbit, ready for operation when needed as a replacement for GOES-8 or GOES-10. After showing signs of imminent failure during 1998, GOES-9 was moved and placed in storage mode at 105 degrees west longitude.

In June 1999, NOAA announced the transition of the surplus spacecraft GOES-7, which had been launched in 1987, to 175 degrees west longitude to support the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT) program, a public service satellite telecommunications network that links educational institutions, regional organizations, and governments in the Pacific islands region. The 23-year-old satellites, GOES-2 and GOES-3, that PEACESAT was previously using for communications were finally brought out of orbit and replaced by the sturdier GOES-7. The PEACESAT program, a partnership with the University of Hawaii, uses a NOAA Command and Telemetry Processor that is no longer needed to operate the newer GOES satellites.

NOAA participated with NASA and the U.S. Geological Survey in planning to support Landsat 7, which was successfully launched in April 1999. NOAA operational responsibilities for Landsat were transferred to NASA and the U.S. Geological Survey later in the year.

A number of key milestones in NOAA's efforts to promote the commercial remote-sensing industry occurred in FY 1999. With the launch of the world's first 1-meter commercial remote-sensing satellite, Space Imaging's Ikonos 2, in September 1999, the United States regained its qualitative lead in the global imagery market, thus fulfilling the vision of Congress and the Administration for a robust U.S. space industry. NOAA also licensed the world's first hyperspectral satellite systems in 1999. Four

amendments and four foreign agreements were also approved, enabling U.S. licensees to garner the investment and foreign partnerships needed to sustain these complex systems. Finally, in keeping with its statutory responsibilities, NOAA established a monitoring and compliance program, including the recruitment of the first two full-time officers.

In the area of international cooperation and activities, NOAA continued its involvement in activities associated with the Committee on Earth Observation Satellites (CEOS). The former NESDIS Assistant Administrator headed the CEOS Strategic Implementation Team which is involved in further development of the Integrated Global Observing Strategy (IGOS). A NESDIS senior official chaired the CEOS Disaster Management Support Project, spearheading the pursuit of a number of activities in conjunction with other disaster management and space agencies.

NESDIS cohosted the U.S.-Japan Global Observation Information Network (GOIN) Symposium and Workshop in Honolulu, Hawaii, in March 1999 with the University of Hawaii and NASA, at which Internet-based global exchanges of data sets for environmental monitoring and scientific work were demonstrated. Begun as a demonstration project under the U.S.-Japan Common Agenda, the continuation of the GOIN work is being transferred to CEOS.

Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator, Dr. D. James Baker, provided the keynote address at the 2nd Global Disaster Information Network (GDIN) meeting held in Mexico City in May 1999. GDIN continues to build a constituency and framework to share disaster information among data providers and data users to lessen the loss of life and property from natural and technological disasters.

At the request of the U.S. Agency for International Development (USAID), NESDIS participated in U.S. Government-sponsored Hurricane Mitch reconstruction and development activities in Central America. The NESDIS activity, part of a DoC-wide initiative, involves the installation of a regional satellite ground receiving station. This will

enhance access to and the use of GOES and Polar-orbiting Operational Environmental Satellite (POES) imagery by the national meteorological and hydrological agencies in Central America for weather forecasting and disaster preparation, management, and mitigation. As requested by USAID Brazil, NESDIS continued to work with the government of Brazil, using satellite imagery to detect wildfires that threaten the Amazon rainforest.

The NOAA Administrator headed the U.S. Government delegation to the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna, Austria, in July 1999. NESDIS specialists participated in panels focusing on the use of satellites for weather forecasting, environmental monitoring, and disaster management.

In 1999, NOAA's National Geodetic Survey (NGS) conducted an evaluation of the suitability of RADARSAT imagery for delineating shoreline for hydrographic support and nautical charting in Alaska. As an aid in change analysis, NGS used high-resolution, spaceborne imagery as a reconnaissance tool to evaluate the temporal accuracy of previously mapped shoreline data. NGS began experimenting with a wide variety of spaceborne commercial imagery to conduct similar studies of shoreline accuracy.

NGS observed radio signals from the U.S. GPS satellites to develop new models of the ionosphere. NGS created a global model of Total Electron Content, using GPS data from globally distributed International GPS Service for Geodynamics (IGS) stations and its own National GPS Continuously Operating Reference Station (CORS) network. The model compares favorably with those produced by other IGS analysis centers. Specific software was developed that continuously applies an ionospheric correction to GPS carrier phase measurements.

As chair of the Federal Geodetic Control Subcommittee of the Federal Geographic Data Committee, NGS continued its work to strengthen ties between the GPS positioning and navigation communities and to ensure that GPS meets the needs of Federal civilian service users. Also, as chair of the GPS Interagency Advisory Council, NGS led in the

development of recommendations to the Interagency GPS Executive Board (IGEB) regarding the design and funding for future civilian GPS signals.

Throughout 1999, DoC played a critical role in the management of GPS as a member of the IGEB. To support the day-to-day functions of the board, NOAA and the Technology Administration (TA) collaborated to establish a permanent IGEB Executive Secretariat within the DoC building. The new office includes representatives from NOAA, TA, and other departments. NOAA, TA, and the National Telecommunications and Information Administration (NTIA) participated in a number of IGEB working groups, including technical and budgetary efforts that led up to and stemmed from Vice President Gore's January 1999 announcement of a $400 million GPS modernization initiative. To highlight the civilian interest in GPS modernization, DoC led an assessment of U.S. industry uses of GPS. As part of this assessment, Deputy Secretary of Commerce, Robert Mallett hosted a roundtable meeting with industry executives to hear how their businesses might be affected by a more robust GPS service.

DoC also served on a number of U.S. delegations that met with Europe and Japan to promote GPS and discuss possible areas of international cooperation in satellite navigation. TA served as the lead representative of U.S. commercial interests on these delegations. In October 1999, DoC chaired and hosted the first meeting of the bilateral U.S.-Japan working group on commercial and scientific uses of GPS—one of three working groups created by President Clinton and Japanese Prime Minister Obuchi.

During FY 1999, TA's National Institute of Standards and Technology (NIST) provided metrology support, modeling, and development activities for a variety of aeronautics and space activities. NIST scientists and engineers worked with NASA on more than 45 projects. NIST developed design requirements for a superaccurate atomic clock to be used in Earth orbit—the Primary Atomic Reference Clock in Space (PARCS)—and developed a critical element for the space clock. NIST continued to supply the Jet Propulsion Laboratory with time and frequency

reference services for the NASA Deep Space Network. NIST completed a project to supply NASA with software tools to evaluate fire-detector systems in high-bay spaces, such as those used in staging and assembly for Space Shuttle missions.

NIST also developed and delivered to NASA's Johnson Space Center a special refrigerator system to be used to liquefy oxygen to generate the liftoff fuel on Mars for the return to Earth of a future Mars lander. NIST produced a mathematical model to take into account the effects of convection during crystallization, which will aid NASA in the interpretation of crystal growth under microgravity conditions. NIST scientists and engineers developed special instrumentation used to calibrate the x-ray optics and detectors of NASA's orbiting Chandra X-ray Observatory and performed dimensional verification measurements of the analyzer element of Chandra. Finally, NIST demonstrated new high-sensitivity detector technology suitable for creating imaging arrays for Goddard Space Flight Center's Constellation-X satellite program and other NASA Earth and space applications.

During FY 1999, DoC continued its efforts to foster an economic and policy environment that promotes the global preeminence of the U.S. commercial space industry. TA and the International Trade Administration (ITA) served as advocates for the U.S. commercial satellite-imaging industry during high-level interagency meetings and government-to-government meetings on U.S. remote-sensing policy regarding Canada, Greece, Israel, Italy, Japan, Korea, Russia, and Spain. TA and ITA also represented the interests of the U.S. launch and satellite industries during preparations for annual consultations with China, Russia, and the Ukraine on commercial space launch services. In November 1999, the United States and Russia finalized an exchange of diplomatic notes, which amended the U.S.-Russia Commercial Space Launch Agreement and increased the level of trade in launch services allowed under the agreement.

TA and ITA also participated in a White House–led review of the U.S. space launch bases and ranges. The review was initiated in March

1999 in light of increasing commercial space launch activity over the past 5 years, particularly at Cape Canaveral Air Station in Florida and Vandenberg Air Force Base in California. During the review and the development of recommendations for future launch range management, DoC provided inputs reflecting the concerns of the commercial launch industry.

In FY 1999, ITA continued to assist the U.S. aerospace industry in competing in the global marketplace. In April, ITA and other Federal agencies mounted a campaign to persuade the European Union to withdraw or suspend its new regulations restricting civil aircraft that are modified with noise reduction devices, including aircraft engine "hushkits." These regulations threaten to erode U.S. sales in Europe and disrupt efforts to establish a more stringent noise standard in the International Civil Aviation Organization. The regulations have not been overturned, but U.S. efforts continued in this regard. ITA was instrumental in securing tariff waivers for U.S. exports of aircraft to Russia under a bilateral agreement on Aircraft Market Access. ITA also supported the efforts of the U.S.-China Joint Committee on Commerce and Trade to expand intergovernmental cooperation and trade in civil aviation and airports.

To promote U.S. aerospace exports, ITA sponsored Aerospace Product Literature Centers at seven major international exhibitions and air shows in Australia, China, France, Malaysia, Russia, Taiwan, and the United Kingdom. The program generated more than 8,500 trade leads for U.S. firms. ITA also supported U.S. contract bids in international competitions to supply helicopters, commercial transport aircraft, satellites, and space launch vehicles. ITA sponsored the U.S. National Pavilion at the Paris Air Show in June 1999. The pavilion housed the exhibits of more than 125 companies, U.S. trade associations, and U.S. Government agencies. This marked the first appearance of the commercial space industry at the Paris Air Show.

ITA also continued its work to support U.S. access to satellite markets overseas through a variety of bilateral and multilateral initiatives. Under the World Trade Organization Agreement on Basic Telecommunications Services, ITA supported the U.S. Trade

Representative's office in monitoring several aspects of the agreement, including provisions relating to market access for satellite service providers. ITA supported the inclusion of certain satellite products in the Information Technology Agreement II, with the goal of reducing tariffs and facilitating increased trade. With regard to Japan, ITA monitored compliance with the 1990 U.S.-Japan Satellite Procurement Agreement.

ITA updated its market data and projections on sales of aerospace and commercial space products and services, including aircraft, helicopters, satellites, and space transportation services. This information was published in the *2000 U.S. Industry and Trade Outlook.*

In March 1999, to comply with the 1998 National Defense Authorization Act, the Bureau of Export Administration (BXA) transferred its export licensing authority for commercial communications satellites to the Department of State (DoS). Because DoS was not staffed to meet the additional workload, satellite export applicants were subjected to significant licensing delays. Furthermore, under the monitoring provisions of the legislation, U.S. manufacturers were forced to obtain DoS-issued Technology Transfer Agreements for the launch support of satellites previously licensed by DoC, even when the customer or launch service provider was a North Atlantic Treaty Organization (NATO) ally. The change in jurisdiction caused harm to U.S. satellite and component makers and incited a backlash from potential foreign buyers of U.S. satellites. Satellite manufacturers detailed many of these problems in testimony to Congress.

In FY 1999, BXA submitted its fourth annual report to Congress on *Offsets in Defense Trade*, which includes an analysis of impacts on the U.S. aerospace sector. Offsets are industrial compensation practices, required as a condition of purchase by foreign governments in either government-to-government or commercial sales of defense articles and services. Imports of aircraft and aircraft engine parts more than doubled from 1993 to 1998, thereby displacing U.S. subcontractors to a degree. Offsets are thought to have played a significant role in this trend.

BXA participated in an interagency group that conducted exploratory discussions with Canada and the Netherlands with the objective of reducing or eliminating offsets. The group also contacted NATO and other allies requesting discussion on offsets. In June 1999, BXA Assistant Secretary Roger Majak testified before the House Committee on Government Reform on the subject of defense trade offsets. Rising congressional interest culminated in the Defense Offsets Disclosure Act of 1999. This law created a Presidential Commission that will develop a strategy to eliminate offsets.

During FY 1999, NTIA continued to provide spectrum for Federal agencies to operate their respective radiocommunications systems associated with aeronautical and space operations. In addition, NTIA reviewed and approved Federal agency requests for spectrum to support future aeronautical and space radiocommunications systems. This includes 2 systems for DoC valued at $2.05 billion, 24 systems for NASA valued at $2.066 billion; and 3 systems for the Air Force. NTIA also coordinated 30 U.S. satellite systems internationally with other countries through the International Telecommunications Union (ITU) to prevent interference to these systems as well as interference from these systems to other administrations' receivers.

NTIA participated in various ITU plenipotentiary conferences, radio conferences, technical study groups, and other forums. NTIA began its preparations for ITU World Radiocommunication Conference 2000 (WRC-2000) immediately after the close of WRC-97 and continued to do so through FY 1999. NTIA and the Federal Communications Commission developed draft U.S. proposals for WRC-2000 agenda items, which include a spectrum for third-generation wireless and sharing between nongeostationary and geostationary fixed satellite service systems. NTIA also contributed significantly to the Conference Preparatory Meeting by providing numerous technical papers on the aeronautical and satellite spectrum issues that were addressed at WRC-2000. These WRC positions and Conference Preparatory Meeting technical papers were also coordinated by NTIA with the Commission on Inter-American Telecommunications (CITEL).

NTIA undertook a number of policy initiatives regarding satellites and other space-based communications systems. Specifically, NTIA provided policy guidance on the restructuring of the International Telecommunications Satellite Organization (INTELSAT) and the privatization of the International Mobile Satellite Organization (INMARSAT).

In FY 1999, the Patent and Trademark Office granted 795 U.S. patents relating to aeronautics and space. The inventions disclosed in the patents broadly encompassed aircraft, missiles, satellites, space vehicles, and ancillary devices. These inventions promote innovation and discovery in vital technology fields, including the aeronautics and space industries.

Department of the Interior

DoI

The Landsat 7 satellite was launched successfully on April 15, 1999. NASA and the U.S. Geological Survey (USGS) are jointly managing the program. Landsat 7 is extending the medium-resolution global land coverage that has been the hallmark of the Landsat program since 1972. A complete global archive of relatively cloud-free coverage was collected during the first 6 months of operation; such coverage has not been achieved in nearly a decade. All Landsat 7 data received at the primary ground station at the USGS Earth Resources Observation System (EROS) Data Center are being archived and made available to the public in digital format within 24 hours of collection.

The USGS EROS Data Center Earth Observing System Distributed Active Archive Center, which is funded by NASA, supported four missions in 1999, including the prelaunch, instrument checkout, and operations activities of Landsat 7 and the prelaunch and operations readiness activities in support of the Terra mission. USGS staff participated in the calibration of the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument that is collecting information on Earth's environment.

The USGS Astrogeology Program continued to make significant contributions to the exploration of the solar system. NASA's Galileo

mission to Jupiter continued to return exceptional images of Io and other Jovian satellites that give major insight into the surficial processes at work on those moons. The Deep Space 1 spacecraft returned image and spectral data from a near-Earth asteroid, leading to new knowledge that perhaps the near-Earth asteroid Braille is related to the much larger and well-studied asteroid Vesta, perhaps as a "chip off Vesta's old block" or as a "sibling" from a larger body that has long since been destroyed. USGS scientists contributed to all these astrogeology efforts.

USGS scientists involved with the Mars Orbital Camera and the Thermal Emission Spectrometer teams of NASA's Mars Global Surveyor mission continue to make observations of surface landforms and composition through those instruments, and they also assist in the selection and monitoring of specific targets on Mars. Unfortunately, the Mars Exploration Program suffered a huge setback with the losses of the Mars Climate Orbiter and the Mars Polar Lander: Two USGS Astrogeology Program scientists have been asked to serve on the Mars Program Independent Assessment Team, which will make recommendations on future Mars exploration strategies.

DoI continued to utilize both the DoD Navstar GPS Precise Positioning Service (PPS) and augmented differential GPS for real-time positioning in wildland areas. Laser rangefinders have also been linked directly to GPS receivers to assist in field work for remote positioning in dangerous or inaccessible terrain. DoI continued to assist the DoT-DoD efforts to expand the Nationwide Differential GPS (NDGPS) by identifying project areas that are out of reach of current differential GPS methods. DoI GPS coordinators continued to identify DoI requirements for specifications of future improvements to military handheld GPS receivers.

The Multi-Resolution Land Characterization Project, a joint activity of the USGS, the Environmental Protection Agency (EPA), NASA, NOAA, and other agencies, had produced medium-resolution, land-cover data from Landsat data for 41 States by the end of FY 1999. The USGS Global Land Cover data base (known as the DISCover land cover layer), which is derived from AVHRR satellite data, is the first and only global

land cover data base to have a statistically based accuracy assessment. Validation was completed in FY 1999 with an average accuracy of 73.5 percent per land-cover category.

The Office of Surface Mining Reclamation and Enforcement (OSMRE) employed GPS in various initiatives in FY 1999. OSMRE used GPS to locate acid seeps as part of its Appalachian Clean Streams Initiative. The Mountaintop Removal Task Force used GPS to locate mine features in the field. GPS mapping saved time and design costs at the Coal Basin reclamation project in cooperation with the State of Colorado. OSMRE and the State of Pennsylvania have monitored the surface effects of longwall mining with GPS techniques.

The Bureau of Indian Affairs (BIA) used remote sensing and GPS to support BIA and tribal initiatives to map land use, inventory natural resources, and conduct environmental assessments. Digital orthophotography and National Aerial Photography Program (NAPP) aerial photography were used as backdrops to model potential flood inundation zones caused by the failure of BIA-managed dams and to delineate the extent of irrigated agricultural lands within BIA irrigation districts on Indian reservations in the Western United States. Digital orthophotography and color-infrared NAPP photography were used to create maps to support the clearing of military ordnance from the Badlands Bombing Range, Pine Ridge Reservation, South Dakota. Landsat 7 data were enhanced to map the perimeter and relative burn intensity of several large wildfires in Nevada as part of a joint BIA-Bureau of Land Management firefighting effort. The BIA also expanded the applications of both civilian and military (encrypted) GPS receivers in natural resource planning, inventory, and mapping.

The National Park Service (NPS) used Landsat and Satellite Pour l'Observation de la Terre (SPOT) data, along with conventional aerial photography and digital orthophotography, to map and monitor land cover, vegetation, cultural features, and other specific features in many National Parks, from Alaska to Florida. Approximately 400 GPS units were used to support mapping and navigation needs for a variety of resource management and maintenance applications.

The USGS cooperated with the NPS in FY 1999 to use aerial photography and extensive field data to classify and map vegetation communities in Fort Laramie National Historic Site, Wyoming; Agate Fossil Beds National Monument, Nebraska; and Wind Cave National Park, South Dakota. The Gap Analysis Program cooperated with State and local partners to complete its analysis of the conservation status of vertebrates and plant communities in 14 States, using Landsat data, wildlife habitat surveys, and extensive field sampling. Other research efforts employed various types of telemetry to track terrestrial and marine wildlife and assess habitat use and availability. Hyperspectral imaging was used to detect and map invasive plants.

The Minerals Management Service (MMS) used GPS as part of a U.S.-Mexico boundary survey to identify shoreline points to calculate the part of a proposed offshore boundary that is not already legally defined. The MMS also supported the analysis of AVHRR data and altimetry data from the Ocean Topography Experiment (TOPEX) and European Remote-Sensing Satellite-1 (ERS-1). Partners included the Scripps Institution of Oceanography (La Jolla, California), Louisiana State University, the University of South Florida, and Texas A&M University.

Remotely sensed data from satellites and aircraft sensors and GPS technology continued to play an important role in the Bureau of Land Management's efforts to sustain the health, diversity, and productivity of the public lands. The data provided critical information to resource specialists for their inventory, assessment, modeling, and monitoring efforts. Data from traditional and digital aerial cameras and multispectral and hyperspectral sensors were supplemented by Geographic Information System (GIS) technology to support management activities associated with wildlife habitat, wilderness, recreation, rangeland, timber, fire, minerals, and hazardous materials.

The U.S. Fish and Wildlife Service (FWS) found innovative ways to use GPS and aircraft for the rapid creation of data bases from field data for wildlife and habitat inventories. For example, the Office of Migratory Bird Management has implemented a data recording system that automatically

incorporates GPS locations for all aerial waterfowl survey observations and generates a ground track of the aerial flight path. FWS offices regularly use GPS units for navigation, both on water bodies and in roadless areas. GPS units are also used to create data layers for use in GIS programs, particularly marking facility locations and boundaries of management activities such as controlled burns, wildfires, and hunting units.

The USGS National Civil Applications Program (NCAP) provides secure facilities for Federal civil agencies to acquire and process classified satellite data for applications such as land and resource management, global change research, environmental monitoring, and disaster detection and mitigation. In 1999, NCAP staff and the Department of Defense continued to test the prototype Hazard Support System, which will provide near-real-time warnings of wildland fires in the United States, and to monitor and report on volcanic activity and associated volcanic ash clouds worldwide. The Global Fiducials Library became operational, providing the scientific community with digital classified satellite data collected over selected worldwide sites for long-term environmental monitoring.

The USGS used satellite data to measure the volumetric changes of glaciers in Washington and Montana. These measurements enhanced the USGS Benchmark Glacier program that focuses on the response of glaciers to climate changes. The program continued to be carried out in cooperation with the NPS at North Cascades and Glacier National Parks. The USGS used RADARSAT and ERS-2 Synthetic Aperture Radar (SAR) images to monitor the catastrophic retreat under way at the Columbia Glacier in Prince William Sound, Alaska. Compared to Captain George Vancouver's observation from two centuries ago, Columbia Glacier is the only remaining tide water glacier in southern Alaska that had not retreated. In cooperation with glaciologists at the University of Colorado, the USGS used a combination of SAR images and vertical aerial photography to measure the glacier dynamics in the critical terminus region.

The USGS developed an algorithm that incorporates the effect of grain size growth to extract snow depth from the passive microwave observations obtained by the Special Sensor Microwave Imager (SSM/I)

on the Defense Meteorological Satellite Program (DMSP) satellite. The brightness temperature of a snow pack in the microwave wavelength bands depends not only on the snow depth but also on the internal snow pack properties, particularly the grain size, which is highly variable through the winter. Previous algorithms did not include this effect and have yielded erroneous estimates of snow depth. This algorithm is being used in a joint USGS-NASA study of the fresh water input to the Arctic Ocean that results from the melting of the Siberian snow pack. Fluctuations in the snow pack may influence the response of the Arctic Sea ice cover to anticipated global warming.

Interferometric Synthetic Aperture Radar (InSAR) data were used to detect and measure land-surface displacements in the Las Vegas (Nevada) and Santa Clara (California) valleys caused by the deformation of ground-water aquifer systems caused by hydraulic stresses, such as seasonal and long-term changes in ground-water pumping. These data have also revealed the presence of previously unmapped faults in urban areas, such as an extension of the Silver Creek fault in downtown San Jose, California.

The USGS Volcano Hazards Program expanded its use of remotely sensed data in FY 1999. Applications include surface deformation monitoring, thermal monitoring, detection and tracking of volcanic ash clouds, and topographic mapping. Networks were expanded at two hazardous volcanoes sites, Long Valley, California, and Mauna Loa, Hawaii, that use GPS to monitor deformation. Hawaii Volcano Observatory scientists cooperated with scientists at the University of Hawaii to test the use of GOES thermal imagery from the Internet to monitor the ongoing eruption at Kilauea. Imagery was successfully acquired from classified sources to produce a new, detailed digital elevation model of Augustine Volcano.

USGS scientists applied satellite-based InSAR techniques to study volcanoes in Alaska by producing deformation measurement at tens-of-meter horizontal resolution with centimeter to subcentimeter vertical precision. Using this technique, scientists discovered that the center of Okmok Volcano subsided 140 centimeters as a result of the 1997 eruption. It was also demonstrated that Westdahl Volcano has been inflating with

magma since 1992. Based on the timing of recent eruptions at Westdahl and the fact that it has been inflating for 7 years, a new eruption can be expected within the next several years. As we increase our understanding of the use of satellite interferometry to detect inflation at volcanoes that appear inactive, we will improve our ability to anticipate volcanic eruptions and, thus, to mitigate volcanic hazards.

The USGS Alaska Volcano Observatory continued to utilize up-to-the-minute satellite data and computer modeling techniques to monitor volcanic ash clouds that spread into the atmosphere thousands of feet above Earth's surface as a result of volcanic activity in the North Pacific region. The proximity of more than 40 active volcanoes in Alaska to the Anchorage International Airport, the largest cargo-handling facility in the United States, has created a potentially dangerous situation. In FY 1999, the Observatory provided information about airborne volcanic ash from several eruptions to the FAA, U.S. Air Force, and National Weather Service to assist in aircraft hazard mitigation and weather forecasting.

The USGS National Water Quality Assessment (NAWQA) program used color-infrared and black-and-white NAPP aerial photographs to create high-resolution rectified digital images to map land-use boundaries within a 500-meter buffer area around water wells that are part of the NAWQA ground-water quality monitoring network. USGS personnel continued to utilize the land-use delineations to define relationships between land-use characteristics and ground-water quality.

FEDERAL COMMUNICATIONS COMMISSIONS

FCC

In FY 1999, the FCC continued with great strides in ensuring that satellite regulation and policy were in the public's best interest. The FCC made a number of significant authorization decisions during this time: (1) the authorization of NewSkies, a spinoff of INTELSAT, to provide domestic and international Fixed Satellite Service (FSS) in the United States for the first time; (2) the merger of U.S. Satellite Broadcasting and DIRECTV, which would enable DIRECTV to become a stronger competitor in the multichannel Direct Broadcast Service video programming distribution market; and (3) the authorization of direct access to the INTELSAT satellite system for international service to benefit U.S. users of INTELSAT by allowing them to deal directly with INTELSAT for satellite services, thus eliminating go-between expenses. In February 1999, the FCC made available to the public electronic filing for satellite and Earth station licenses. Currently, approximately 10 percent of all filings are done electronically and save 30 to 50 days in processing time.

The FCC authorized two commercial satellites for launch in October 1998: WorldSpace's AFRISTAR, providing multimedia broadcasting, and GE Americom's GE-5, an operational Ku-band satellite. The FCC also approved SEDSAT, an experimental nongeostationary satellite (NGSO), for launch in October. The FCC authorized the launching of two

PanAmSat geostationary commercial satellites: PAS 8 in November 1998, providing C/Ku-band operations in the Asia-Pacific region, and PAS-6B in December 1998, providing Ku-band "direct-to-home" broadcasting to Latin America. In May 1999, Loral launched Orion 3. The failure of the launch vehicle resulted in the satellite being in lower-than-expected orbit without the possibility of recovery. In September 1999, Echostar launched Echostar 5, providing coverage to Alaska and Hawaii and extending the available lineup to 500 channels. Furthermore, the Echostar 5 satellite transmits high-definition programming, Internet, and interactive services.

In addition, the FCC authorized 43 NGSO's for launch in FY 1999. The provisioning of Globalstar's NGSO communications network constituted the bulk of the satellites (32) distributed among 8 launches, with 4 satellites in each launch. Iridium launched nine NGSO satellites, and Space Imaging Corporation launched two NGSO satellites, Ikonos 1 (which experienced launch failure) and Ikonos 1B (which provides commercial remote imaging).

DEPARTMENT OF AGRICULTURE

USDA

USDA's research and operational programs used remotely sensed data and related technologies to monitor, assess, and administer agricultural and forestry resources. The Agriculture Research Service (ARS) enhanced remote-sensing knowledge and developed productive applications at research facilities located throughout the United States. At Weslaco, Texas, the ARS Integrated Farming and Natural Resources Unit used airborne video data integrated with Global Positioning System (GPS) and Geographic Information System (GIS) technologies to detect and map the aquatic weeds, hydrilla, and water hyacinth in the Rio Grande River in extreme southern Texas. The unit also developed and delivered GIS maps to the Texas Parks and Wildlife Department and the Lower Rio Grande River Water Districts, which can use the maps to control the spread of these weeds. At Weslaco, aerial digital images in conjunction with yield monitor data were collected from 20 grain sorghum fields owned by Rio Farms, Inc., Monte Alto, Texas. Rio Farms managers have used the aerial images and yield maps, produced from the yield monitor data, to improve farm management.

The ARS Hydrology Laboratory initiated work to develop methods for retrieving soil moisture information from satellite-borne microwave sensors. Scientists conducted experiments at ARS facilities in Oklahoma

using aircraft prototypes of these instruments. At the ARS Jornada Experimental Range, the Hydrology Laboratory collected laser scanning data and visible, thermal infrared, and video imagery to infer surface temperature, albedo, vegetation indices, roughness, and other land-surface characteristics. These parameters are to be used as inputs for land-surface models, coupled with atmospheric models. In preparation for the launch of NASA's Earth Observing System (EOS) AM1 satellite (now called Terra), the Hydrology Laboratory has flown multispectral thermal infrared sensors (TIMS and MASTER) over the Jornada Experimental Range to estimate surface emissivity and temperature. ARS will use the latter to estimate the surface-sensible heat flux. This approach has been successfully demonstrated with data acquired over the El Reno Grazing Lands facility in Oklahoma as part of the Southern Great Plains 97 experiment.

At ARS laboratories in Ames, Iowa, ARS researchers continued to develop methods for detecting weeds within corn and soybean canopies. Scientists measured and recorded the leaf spectra of weeds, corn, and soybeans grown in single species plots and in competition. ARS made concurrent reflectance measurements with a broadband radiometer of plots with different weed densities and species composition. To discriminate nutrient stress and its potential impact on yields, ARS measured the reflectance of corn produced from various populations and nitrogen management strategies. To determine the effect of soil background on crop detection, scientists developed a seasonal reflectance library for corn, soybeans, and wheat with different tillage and crop residue practices.

The ARS Great Plains System Research Unit in Ft. Collins, Colorado, the ARS Southwest Watershed Research Center in Tucson, Arizona, and Michigan State University brought private, nonprofit, and public-sector groups together in Arizona, Colorado, New Mexico, and Nebraska to develop techniques for estimating the amount and spatial distribution of total standing, green, and senescent biomass in grassland ecosystems. The project was designed to demonstrate how remote sensing can be cost-effectively used in managing these diverse and important natural resources.

In Phoenix, Arizona, the U.S. Water Conservation Laboratory (USWCL), in cooperation with the University of Arizona, designed and tested a system for acquiring images from sensors mounted on agricultural implements. Scientists used data from the system to verify a new chlorophyll index that shows promise as an indicator of crop fertilizer needs. In a separate study using the Free Air Carbon dioxide Enrichment (FACE) facility, USWCL used measurements of plant reflectance and temperature to assess the response of wheat and sorghum crops to increased atmospheric carbon dioxide. This research will improve our ability to monitor and understand how various global change scenarios will affect agricultural productivity and carbon sequestration. USWCL scientists cooperated with NASA's Stennis Space Center, through a Space Act Agreement, to develop products and applications to manage crops and soils using data from multispectral airborne sensors. Scientists have used the data to develop methods for detecting crop water stress and improving irrigation scheduling with minimal ground-based inputs and no image calibration. USWCL scientists, as members of the NASA Landsat 7 Science Team, combined imagery from the Landsat 7 Enhanced Thematic Mapper-Plus (ETM+) sensor with a grassland growth model to produce daily maps of grassland biomass, root biomass, and soil moisture over a semiarid watershed. These maps allow for better rangeland management and provide a greater understanding of rangeland ecology for addressing soil erosion and drought.

Using remote-sensing technology, the ARS Remote Sensing and Modeling Laboratory (RSML) and the Hydrology Laboratory initiated a long-term experiment to evaluate the economic and environmental impact of four alternative farming practices on surface and subsurface water quality. They mapped subsurface flow patterns with Ground Penetrating Radar and linked them to crop yields and remotely sensed hyperspectral data. Their remote-sensing assessment of the spatial and temporal variability of crops will benefit farmers and various agricultural industries by providing a watershed-scale demonstration site at which crop yields, profitability, and environmental impact can be compared under identical hydrogeological setting and climatic conditions.

In a field study cosponsored by Stennis Space Center and ARS, RSML investigated the use of Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) hyperspectral data to detect nitrogen deficiency and water stress in crops. Scientists conducted the study at Shelton, Nebraska, over an irrigated corn field with 20 variable-rate nitrogen plots. RSML acquired coverage from three NASA AVIRIS flights during the growing season and made extensive ground measurements of the agronomic and spectral characteristics to facilitate the development of models to identify crop stress. Over spring wheat fields in Montana, North Dakota, South Dakota, and Minnesota, RSML identified and monitored crop stress throughout the growing season. Through cooperative research with the USDA's Foreign Agricultural Service (FAS), scientists evaluated models for assessing spring wheat production in Siberia and Kazakhstan. Also, RSML used fluorescent sensing to detect ozone damage, ultraviolet radiation damage to vegetation, and the effect of increased carbon dioxide. RSML demonstrated that remote sensing can accurately assess tropospheric environmental problems.

Researchers at the ARS Western Integrated Cropping Systems Research Unit in Shafter, California, continued to develop procedures for detecting and managing water stress and pest infestations. The Shafter Airborne Multispectral Remote Sensing System (SAMRSS), which acquires high-resolution imagery in the visible, near-infrared, and thermal infrared, was flown on 30 missions. Using this imagery and data from ground-based collections, researchers developed procedures for detecting early infestations of spider mites in cotton and the onset of water stress. Researchers at Shafter cooperated with colleagues from Opto-Knowledge Systems, Inc., and NASA in studying the use of hyperspectral imagery from AVIRIS in agricultural applications. In cooperation with Cotton, Inc., researchers purchased a cotton yield monitor and installed it on a cotton picker to determine spatial relationships between yields and remotely sensed variables. They determined that the spatial variability in cotton yields across a field can best be estimated using midseason multispectral imagery.

The ARS Rangeland Resources Research Unit at the High Plains Grasslands Research Station in Cheyenne, Wyoming, collected Very Large Scale Aerial (VLSA) images of soil erosion plots at the Central Plains Experimental Range. To improve rangeland management, researchers there compared measurements made from this aerial imagery with hand-collected data of bare ground, plant cover, microtopography and microflow patterns. In cooperation with the Department of the Interior's Bureau of Land Management, the State of Wyoming, and private ranchers, the unit has used VLSA and space imagery for rangeland monitoring that is low-cost and defendable in court. An additional critical component of this research will relate important aspects of rangelands like leaf area of dominant functional plant types to carbon dioxide fluxes and carbon cycling.

At Reynolds Creek Experimental Watershed, the ARS Northwest Watershed Research Center (NWRC) used satellite imagery—Landsat 5 Thematic Mapper and Satellite Pour l'Observation de la Terre (SPOT) 3HRV—to classify accurately shrub steppe and subalpine plant communities. A practical procedure for classifying and mapping intermountain plant communities using satellite imagery was provided to the Bureau of Land Management's Snake River District in Idaho. NWRC also has evaluated multispectral digital aerial photography as a tool to determine stream shading by riparian vegetation and its effects on surface water quality in rangelands. Using Landsat imagery, NWRC quantified leaf area indices for rangeland plant communities for input to water and energy balance models that can be used to estimate rangeland plant production. NWRC also has worked with NASA to develop the use of synthetic aperture radar to map the distribution of frozen soil and soil-water content in rugged terrain.

The ARS laboratory in Sidney, Montana, conducted remote-sensing research for noxious weed identification, mapping, and monitoring crop management. The laboratory used color aerial photography to map leafy spurge infestations in Theodore Roosevelt National Park and the Sheyenne National Grasslands of North Dakota. It subsequently interpreted, digitized, and incorporated the national park's imagery with similar data collected in 1993. The 5-year comparison has provided a valuable

evaluation of leafy spurge growth, distribution, and dynamics within the park. The laboratory also acquired normal color aerial photography of salt cedar stands in Wyoming, Utah, Nevada, and California to develop baseline population levels for studies involving releases of biological control agents. Research continued on the use of aerial videography for monitoring crop development and yield prediction in western North Dakota and eastern Montana. The Montana research project used the remote imagery to develop and assess the success of precision agriculture cropping strategies. Researchers have initiated the same technologies in North Dakota to monitor potato crop development and production. A new hyperspectral radiometer and imaging system will be used to improve weed identification and mapping and provide calibrated data for the multitemporal evaluation of crop development.

The satellite remote-sensing program of FAS, operated by the Production Estimates and Crop Assessment Division (PECAD), remained a critical element in USDA's analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global area, yield, and production. Satellite-derived early warning of unusual crop conditions and production anomalies enabled more rapid and precise determinations of global supply conditions. The FAS/PECAD analysts employed a proven "convergence of evidence" approach to crop assessment—incorporating NOAA Advanced Very High Resolution Radiometer (AVHRR), Landsat, and SPOT imagery; crop models; weather data; U.S. agricultural attaché reports; field travel; and ancillary data to forecast foreign grain, oilseed, and cotton production.

FAS/PECAD accurately forecast 1999–2000 global grain production to within roughly 3 percent of final output. Visual interpretation of high-resolution SPOT satellite imagery provided early warning of significant crop stress in key Russian winter-wheat-producing regions. An analysis of yield-simulation models and vegetative indices derived from AVHRR satellite data indicated where drought impact was most severe and identified crop areas that escaped damage. Subsequent harvest reports verified the FAS/PECAD early-season analysis.

FAS/PECAD personnel have participated in international agricultural research studies in Russia and Kazakhstan, in conjunction with USDA/ARS researchers, to expand and improve crop assessment resources for estimating wheat production in the former Soviet Union. The team has worked closely with agricultural and remote-sensing researchers from the Kazakhstan Space Research Institute and the Institute for Environmental Monitoring in Western Siberia to evaluate and refine the use of yield-simulation models and new satellite sensors. This cooperative research resulted in a valuable exchange of crop-forecasting technology.

FAS remote sensing supported Department of State assessments of food needs in the former Soviet Union, Indonesia, and North Korea. Also, FAS prepared detailed analyses of the record Argentine soybean crop, the bumper wheat crop in Australia, the bumper soybean crop in Brazil, drought in the Ukraine, dryness in China and North Korea, and flooding in Mexico.

The Farm Service Agency (FSA) continued to share with FAS the cost of analyzing imagery of the United States. A timely analysis of U.S. crop conditions, combined with weather data, crop model results, and GIS products, made possible the development of accurate and timely projections and comprehensive evaluations of crop disaster situations. During the 1999 growing season in the United States, the domestic analysts of FAS/PECAD provided early warning on anomalous crop conditions, including severe droughts in the Mid-Atlantic States and Eastern Corn Belt, as well as flooding from hurricanes and subsequent rainfall in North Carolina and southern Virginia. The impact of the sixth consecutive wet spring and early summer on agricultural interests in North and South Dakota was determined and reported in interagency briefings and published on the internal FSA/FAS Web site. FSA continued to be a partner in the National Aerial Photography Program (NAPP) and the National Digital Orthoquad Program (NDOP). FSA started field-reengineered business processes that combine the use of digital orthophotography, GIS, GPS, and satellite imagery to replace the use of hard-copy NAPP aerial photography and 35-millimeter slides.

The USDA Forest Service provided support to the Selection Committee for the NASA Research Announcement on Agriculture, Forestry, and Range Management by contributing three members to the selection panel. A proposal from the Forest Service's Fire Sciences Laboratory for Mapping Fire and Fuels Characteristics Using Remote Sensing and Biophysical Modeling for Operational Fire Management was selected by the committee. This project will provide researchers at the Forest Service and universities with vegetation maps of areas prone to wildfires, allowing firefighters to determine which plants are more likely to fuel wildfires and better predict the paths of such fires.

Project Redsky, a DoD/Forest Service experiment to detect fires using DoD satellites, continued in 1999. The Forest Service also has supported the implementation and testing of the Hazard Support System at the U.S. Geological Survey's Reston, Virginia, campus. This system, which warns of the outbreak of wildfires and volcanic eruptions, is a joint program among the DoD, the U.S. Geological Survey, NASA, and other Government agencies. The Langley Research Center FireSat Team provided airborne measurements during a series of controlled fires in Gila National Forest; the measurements were conducted to validate the performance of the Hazard Support System.

The Forest Service continued to study the use of Light Intersection Direction and Ranging (LIDAR) data to create three-dimensional structure maps for forested lands. A NASA C-130, carrying the Laser Vegetation Imaging Sensor (LVIS), mapped a 200-square-mile forest area in northern California as a precursor to the launch of the Vegetation Canopy Lidar (VCL) satellite scheduled for launch in September 2000. The California flights will allow scientists to acquire VCL-like data that will be used to fine-tune data analysis methods.

The National Agricultural Statistics Service (NASS) used remote-sensing data to construct area frames for statistical sampling, to estimate crop area, to create crop-specific land-cover data layers for GIS, and to assess crop conditions. For area frame construction, NASS combined digital Landsat and SPOT data with U.S. Geological Survey digital line-graph

data, enabling the user to assign each piece of land in a State to a category, based on the percentage of cultivation or other variables. NASS implemented a new remote-sensing based area frame and sample for Mississippi. The remote-sensing acreage estimation project analyzed Landsat data of the 1998 crop season in Arkansas, North Dakota, and South Dakota to produce crop acreage estimates for major crops at State and county levels, plus a crop-specific categorization in the form of a digital mosaic of Thematic Mapper scenes distributed to users on a CD–ROM. For the 1999 crop season, NASS headquarters and several NASS field offices entered into partnership agreements with State organizations to decentralize the Landsat processing and analysis tasks. Technicians collected data for 1999 acreage estimation analysis in Arkansas, Illinois, Mississippi, New Mexico, and North Dakota. Vegetation condition images based on AVHRR data were used with conventional survey data to assess crop conditions. NASS employed this imagery to monitor the 1999 drought in Mid-Atlantic States.

The Natural Resources Conservation Service (NRCS) continued its cooperative partnership with Federal, State, and local agencies in developing 1-meter digital ortho-imagery coverage of the Nation through both NDOP and NAPP. By year's end, approximately 1,800 counties will have complete digital ortho-imagery coverage. NRCS and FSA jointly awarded an innovative contract for the development of digital color infrared ortho-imagery for Hawaii. Imagery acquired for Hawaii will be fully digital and integrated with data collected by an onboard inertial measuring unit and dual-band GPS. The inertial measuring unit and GPS data significantly reduce the need for obtaining costly ground control to generate digital orthoimagery to meet national map accuracy standards. NRCS continued to work with the Massachusetts Institute of Technology to make seamless digital orthoimagery data accessible over the Internet.

NATIONAL SCIENCE FOUNDATION

NSF

It is now widely recognized that Coronal Mass Ejections (CME) on the Sun are responsible for the most dramatic effects on Earth's atmosphere. Enabled by NSF support, recent progress has been made in understanding the relationship between CME's and regions of high solar wind flow that rotate with the solar atmosphere. Scientists have isolated specific changes to the Sun's magnetic field that result in CME's, a result that gives hope for eventually predicting the occurrence of these explosions. Scientists have successfully employed advanced modeling, using observations of the solar magnetic field as input, in determining the three dimensional flow of solar wind plasma away from the Sun.

NSF researchers have also made progress in modeling the response of the magnetosphere to variable solar wind input. A new modeling technique called Hall Magnetohydrodynamics has been successful in modeling the critical role of magnetic reconnection in initiating the explosive auroral phenomenon known as a substorm. Scientists have made significant progress in assimilating observational data into models of the magnetosphere and ionosphere, which allows improved determination of important space weather effects such as the transport of energetic particles in the radiation belts and the three dimensional configuration of electric fields and currents in Earth's ionosphere produced by substorms.

Atmospheric studies have concentrated on the middle atmosphere, an altitude region that traditionally has been difficult to observe. New measurement techniques involving radars, lidars, and passive optical instruments have revealed a rich variety of phenomena manifesting the combined processes of chemistry and dynamics. Noctilucent clouds, often referred to as the harbingers of global change, have been studied extensively to identify the temperature and atmosphere composition that give rise to ice crystals in the polar mesosphere. Unique, high-power lidar observations from the Starfire Optical Range near Albuquerque, New Mexico, have produced measurements of wave activity in the middle atmosphere with unprecedented time and spatial resolution. This facility was also used to probe long duration atmospheric contrails created during the Leonid meteor shower in November 1998.

Spread F is a phenomenon in the ionosphere responsible for disruptions to navigation and communications signals at middle and low latitudes. Spread F has been observed recently using combined optical and radar observations from facilities in Puerto Rico and Peru. New radar techniques now enable the separation of temporal and spatial variations to better understand the origin of these irregularities. The role of electric fields and neutral winds in the atmosphere has been evaluated in the structure and evolution of Spread F.

Researchers working under support provided by the NSF have furthered our understanding of star formation in galaxies, learning that the fragmentation of a protostellar cloud early in its collapsing phase seems to work best as a mode of formation for long-period binaries that are widely spaced. Joel Tohline and his associates at Louisiana State University have found that instabilities in the cloud can lead to fission. They have been experimenting with visualizing the mass transfer in interacting binary systems. A self-gravitating rotating protostellar cloud of gas and dust becomes more oblate, deforms into a dumbbell shape, and then divides into a protobinary system. This work was featured in the April–June 1999 issue of *EnVision*.

The Sun is the only star for which we can resolve surface details sufficiently well to provide precise constraints on stellar modeling techniques. Because its activity has a direct impact on terrestrial life, understanding the Sun is a very high scientific priority. With NSF support, Robert Stein has modeled the processes by which energy leaves the Sun's interior, manifests itself as material plume-like flow known as convection, and excites acoustic vibrations that are detectable at the solar photosphere. The models constructed by Stein of Michigan State University, Douglas Braun of the Solar Physics Research Corporation, and other solar astronomers have achieved an unprecedented level of agreement with observations.

Jim Hernstein and his colleagues at the NSF-supported National Radio Astronomy Observatory have used the Very Large Baseline Array (VLBA) to make measurements of water emission from the central regions of the galaxy NGC 4258. The measurements yielded a direct measurement of the distance to this object, about 23.5 million light-years. This result differs significantly from the inferred distance of about 28 million light-years obtained by astronomers using the Hubble Space Telescope. There may be previously unrecognized systematic errors in the Hubble distance scale for the universe.

On April 14, 1999, Geoffrey Marcy of San Francisco State University announced the discovery of three planets around the star Upsilon Andromedae. This is the first time that multiple planets have been discovered around a single star outside the solar system. One of the planets is about three-quarters the mass of Jupiter, and the others are about twice and four times Jupiter's mass.

NSF-supported research has identified the oldest, most distant galaxy found to date. Kenneth Lanzetta of the State University of New York at Stony Brook analyzed data from the Hubble Space Telescope and the Very Large Telescope to find this galaxy. The probable redshift of the galaxy is 6.68. This remarkable achievement was announced on April 14, 1999, and the results were published in *Nature*. Because it has taken billions of years for the light from this galaxy to reach us, the galaxy is being seen as it existed 1 billion years after the Big Bang.

Francois Roddier of the University of Hawaii demonstrated diffraction-limited performance with the NSF-supported Gemini-North 8-meter telescope, using a 36-element curvature-sensing system operating in the near-infrared region of the spectrum. Images of several astrophysical objects were obtained with a resolution of 0.07 arc-seconds. For comparison, the resolution of the Hubble Space Telescope in the same spectral region is approximately 0.15 arc-seconds.

James Stone of the University of Maryland, with Jim Pringle of Princeton University and Mitch Begelman of the University of Colorado, has performed direct numerical magnetohydrodynamic simulations of accretion flows onto black holes. They find that strong convective motions (turbulence) dominate the flow in the inner regions, resulting in a mass inflow rate strongly dependent upon distance. Surprisingly, inflow is everywhere nearly exactly balanced by outflow. The net mass accretion rate is a small fraction of the rate at which mass is supplied from large radii.

NSF support has enabled studies of the evolution of massive stars. Edward Baron of the University of Oklahoma, Peter Hauschildt of the University of Georgia, and Stanford Woosley of the University of California at Santa Cruz have developed realistic theoretical models for several classes of normal and peculiar supernovae. Their new grid of model atmospheres provides a crucial basis for ascertaining whether observations of Type Ia supernovae (SNe Ia) really imply an accelerating universe, as suggested by the Principal Investigator and others, or whether the physical properties of supernovae have evolved since the Big Bang. These models directly confront the observations by predicting the likely spectral evolution of SNe Ia and indirectly by helping to determine the ages of the oldest stars, providing an independent check on the age of the galaxy. For a few minutes, a gamma-ray burst radiates more light than everything else in the universe. Very recently, Baron, Woosley, and University of California at Santa Cruz graduate student Andrew MacFayden have extended their research to the possible connection between supernovae and gamma-ray bursts. These two groups have proposed that similar explosion mechanisms and observational selection may account for the similarities seen in supernovae and gamma-ray burst events.

DEPARTMENT OF STATE

DoS

DoS played a key role in the success of the third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), which was held July 19–31, 1999, in Vienna, Austria. The theme of the conference was "Space Benefits for Humanity in the 21st Century." UNISPACE III, the last global United Nations conference of the century, brought together a unique mix of government and industry representatives to discuss the use of space technology to improve the quality of life and stimulate economic growth around the world. The conference was attended by 2,500 participants from 100 nations. DoS chaired the interagency working group responsible for U.S. participation in the conference.

DoS continued to lead an interagency effort to promote international acceptance of GPS as a global standard for positioning and timing. In November 1998, consultations on GPS issues with a European team headed by the European Commission were held in Brussels. In late September 1999, the first meetings of working groups established under the 1998 U.S.-Japan Joint Statement on GPS Cooperation took place in Washington, D.C.

DoS also facilitated the negotiation and conclusion of memoranda of understanding with the government of India to implement the landmark 1997 agreement between the United States and India on Earth and atmospheric sciences.

DEPARTMENT OF ENERGY

DoE

DoE researchers measured characteristics of high-level cirrus clouds that may affect global warming over the subtropical Pacific for the first time under a jointly funded DoE/NASA atmospheric research project. Sandia National Laboratories conducted the climate studies at the Pacific Missile Range Facility on the Hawaiian island of Kauai for DoE's Atmospheric Radiation Measurement–Unmanned Aerospace Vehicle program. Researchers gathered data using specially designed instruments carried by a remotely piloted aircraft flying at 50,000 feet altitude off Kauai. NASA's Dryden Flight Research Center provided the aircraft used as an aerial platform for the instruments and funded the flight series at the U.S. Navy's Pacific Missile Range Facility under NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program. The scientists' long-range goal is to develop enough information to improve the accuracy of predictive models of climate change. Once the dynamics are better understood, the climate models can reflect that understanding and improve forecasting.

DoE continued to support NASA's space exploration program by maintaining the program and facility infrastructure for providing radioisotope power sources and heater units and developing new, advanced power systems covering a range of power levels required to meet more

stringent power system requirements for future missions. DoE employees began preparing a Final Safety Analysis Report to obtain launch approval for use of radioisotope heater units on the Mars 2001 and 2003 missions. DoE employees also initiated safety analyses to support the potential use of radioisotope power systems on the Europa Orbiter and Pluto/Kuiper Express missions.

Scientists at DoE's Los Alamos National Laboratory anticipated that the controlled crash of NASA's Lunar Prospector spacecraft into the Moon would provide final proof for what they believed they have already measured: the presence of frozen water on the Moon. Although the crash did not kick up a visible cloud of dust, there still could be a small quantity of water buried at the lunar poles.

SMITHSONIAN INSTITUTION

The Smithsonian Institution contributes to national aerospace goals through the activities of the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and the National Air and Space Museum (NASM) in Washington, D.C. SAO conducts a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. NASM, in addition to offering extensive research and education programs, serves as the primary repository for the archives and artifacts of space exploration and discovery.

Successfully deployed from the Space Shuttle in July 1999, the Chandra X-ray Observatory has been orbiting Earth and sending back a steady stream of spectacular x-ray images. Images of objects obtained by Chandra's detectors, including the High Resolution Camera designed by SAO, are received at the Operations Control Center operated for NASA by SAO in Cambridge. SAO is also the site of the Chandra Observatory Science Center, which coordinates research of the space observatory and receives and archives its data for the world astronomical community.

By observing the transits of a suspected planet in front of the star HD209458, SAO astronomers have taken a giant step toward learning about the nature of planets outside our solar system—their size, mass, and density. These observations, made initially by a graduate student advisee of

an SAO scientist, marked the first time that astronomers had directly detected an extrasolar planet, in this case by watching its shadow cross the disk of a Sun-like star. The precise observations allowed astronomers to determine that the suspected planet is a "gas giant," with a density somewhat less than that of Saturn in our own solar system and a size about one-third greater than Jupiter's.

The popular image of nascent planetary systems as thin, spinning pancakes of cosmic dust and debris may be changed by a new computer model that shows how that disk of debris is transformed into a very distinct ring once Pluto-like bodies start to form. By analyzing Hubble Space Telescope images of a suspected young planetary system recently discovered around the star HR 4796A, SAO scientists and their colleagues produced a computer model that suggests the ring around that object probably is a common feature of all planetary systems. Indeed, the well-known Kuiper Belt of asteroids in our own solar system may even be the residual remains of such a ring.

Launched from a Pegasus-XL vehicle on December 5, 1998, the SAO-designed Submillimeter Wave Astronomy Satellite (SWAS) is the first spaceborne observatory to operate at submillimeter wavelengths and has been giving astronomers new clues to some old cosmic mysteries, including how stars—and their accompanying planets—are born. For example, SWAS discovered that large amounts of water seem to pervade the interstellar medium, with particularly copious amounts in the huge molecular clouds thought to be the incubators of newborn stars. By contrast, SWAS has so far failed to detect molecular oxygen in those same interstellar clouds. However, in this case, no news may be perceived as good news, because the apparent absence of molecular oxygen, a byproduct of slow chemical "aging processes" in these clouds, may actually help astronomers to determine their ages.

For nearly four decades, solar scientists have been puzzled by the fact that the high-speed portion of the solar wind travels twice as fast as predicted by theory, with some particles reaching velocities of 2 million miles per hour as they stream out of the Sun and wash over the entire solar

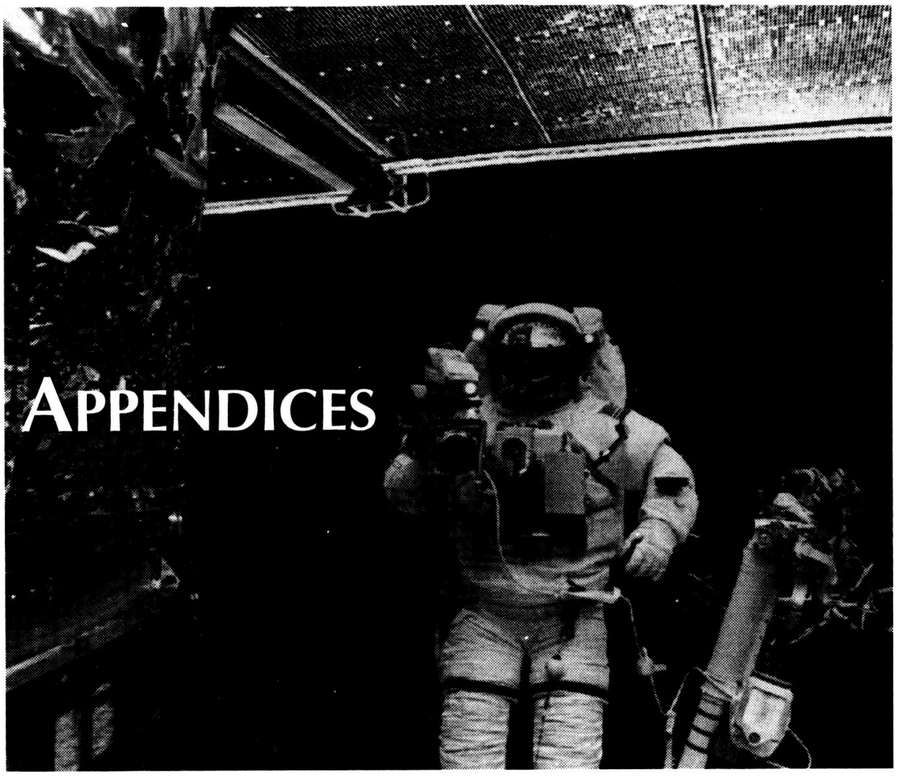
system. Now, observations made with instruments built by SAO and flown aboard NASA's Spartan 201 spacecraft and the international Solar and Heliospheric Observatory (SOHO) have revealed a surprising explanation for this mystery: magnetic waves propel the particles through the corona like surfboarders riding the crests of a cosmic sea. The Sun's outermost atmosphere, or corona, is an extremely tenuous, electrically charged gas that is seen from Earth only during a total eclipse of the Sun by the Moon, when it appears as a shimmering white veil surrounding the black lunar disk. Using ultraviolet coronagraph spectrometers on Spartan and SOHO to create artificial eclipses, SAO scientists detected rapidly vibrating magnetic fields within the corona that form magnetic waves that, in turn, seem to accelerate the solar wind. The electrical charges of the solar wind particles, or ions, force them to spiral around the invisible magnetic lines. When the lines vibrate, as they do in a magnetic wave, the spiraling ions are accelerated out and away from the Sun. Indeed, SAO scientists believe there are magnetic waves in the corona with many different "wiggling periods," or frequencies. Thus, these waves can accelerate various solar wind particles at different rates. For example, SAO researchers found, surprisingly, that the heavier oxygen ions actually move faster than the lighter hydrogen ions.

On July 20, 1999, Vice President Al Gore presented the Smithsonian Institution's Langley Medal to the Apollo 11 astronauts in commemoration of the 30th anniversary of their lunar landing, at a ceremony in NASM's "Milestones of Flight" gallery, next to the Apollo 11 command module *Columbia* and near the Wright Flyer. Special educational activities related to the Moon landing and other space explorations were offered to thousands of NASM visitors on that same day, as well as later during the "Geography from Space" program given as part of National Geography Awareness Week.

"Reflections on Earth," supported in part through a donation by the Honda Corporation, developed a teaching poster distributed to 40,000 middle schools nationwide in an effort to help students understand the use of space technology in the study of Earth and its environment. In

addition, NASM held a teacher workshop on forest biodiversity and remote sensing, supported a variety of field studies, and developed a Web page to disseminate results from this program.

"Earth Today: A Digital View of our Dynamic Planet" is the first exhibit to display near-real-time, global-scale Earth science data sets collected daily by NASA, NOAA, the U.S. Navy, and the U.S. Geological Survey. The NASM program includes daily updates to changing global views of Earth's atmosphere, oceans, and land masses.


APPENDICES

APPENDIX A-1

U.S. Government Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Calendar Year	Earth Orbit[a] Success	Earth Orbit[a] Failure	Earth Escape[a] Success	Earth Escape[a] Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1 [b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32 [c]	0	0	0
1992	26 [c]	0	1	0
1993	28 [c]	1	1	0
1994	31 [c]	1	1	0
1995	24 [c,d]	2	1	0
1996	30	1	3	0
1997	22 [e]	0	1	0
1998	23	0	2	0
1999 *(through September 30, 1999)*	23 [f]	4	2	0
TOTAL	1,440	153	94	15

a. The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.
b. This Earth-escape failure did attain Earth orbit and, therefore, is included in the Earth-orbit success totals.
c. This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle.
d. This counts the five orbital debris radar calibration spheres that were launched from STS-63 as one set of spacecraft.
e. This includes the SSTI Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. Counts multiple communications satellites launched on the same vehicle as one set, such as Globalstar.

APPENDIX A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)

Calendar Year	United States	USSR/ CIS	France[a]	Italy[a]	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India	Israel
1957		2									
1958	5	1									
1959	10	3									
1960	16	3									
1961	29	6									
1962	52	20									
1963	38	17									
1964	57	30									
1965	63	48	1								
1966	73	44	1								
1967	57	66	2	1			1				
1968	45	74									
1969	40	70									
1970	28	81	2	1[b]	1	1					
1971	30	83	1	2[b]	2	1		1			
1972	30	74		1	1						
1973	23	86									
1974	22	81		2[b]	1						
1975	27	89	3	1	2	3					
1976	26	99			1	2					
1977	24	98			2						
1978	32	88			3	1					
1979	16	87			2				1		
1980	13	89			2					1	
1981	18	98			3	1			2	1	
1982	18	101			1	1					
1983	22	98			3	1			2	1	
1984	22	97			3	3			4		
1985	17	98			2	1			3		
1986	6	91			2	2			2		
1987	8	95			3	2			2		
1988	12	90			2	4			7		
1989	17	74			2				7		1
1990	27	75			3	5			5		1
1991	20[c]	62			2	1			9	1	
1992	31[c]	55			2	3			7[b]	2	
1993	24[c]	45			1	1			7[b]		
1994	26[c]	49			2	5			6[b]	2	
1995	27[c]	33[b]			1	2[b]			12[b]		1
1996	32[c]	25			1	3[d]			10	1	
1997	37	19			2	6			11	1	
1998	36	25			2	6			11		
1999 *(through September 30, 1999)*	23	24				2			5	1	
TOTAL	1,179	2,593	10	8	54	56	1	1	113	11	3

a. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.

b. Includes foreign launches of U.S. spacecraft.

c. This includes commercial expendable launches and launches of the Space Shuttle, but because this table records launches rather than spacecraft, it does not include separate spacecraft released from the Shuttle.

d. This includes the launch of ChinaSat 7, even though a third stage rocket failure led to a virtually useless orbit for this communications satellite.

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 3, 1998 USA 140 55A Taurus	Military satellite	Orbital parameters unavailable	
Oct. 5, 1998 USA 141 55C Taurus	Military reconnaissance satellite	Orbital parameters unavailable	
Oct. 9, 1998 Hotbird 5 57A Atlas IIA*	Communications satellite	Geosynchronous	Eutelsat consortium spacecraft
Oct. 20, 1998 UHF F/O F9 58A Atlas IIA*	Military communications satellite	Geosynchronous	
Oct. 23, 1998 SCD2 60A Pegasus*	Environmental data-relaying minispacecraft	769 km 743 km 99.9 min 25.0°	Brazilian spacecraft
Oct. 24, 1998 Deep Space 1 61A Delta II	Experimental spacecraft with ion propulsion engine	Orbital parameters unavailable	
Oct. 24, 1998 SEDSAT 1 61B Delta II	Earth-imaging student spacecraft	1,079 km 547 km 101 min 31.4°	Students for the Exploration and Development of Space
Oct. 29, 1998 Space Shuttle *Discovery* (STS-95) 64A Space Shuttle	Carried experiments on microgravity science and aging	561 km 551 km 95.8 min 28.5°	Second space flight of John Glenn
Oct. 30, 1998 Pansat 64B Space Shuttle	Communications satellite	Orbital parameters unavailable	Amateur student minisatellite
Nov. 1, 1998 Spartan 201-05 64C Space Shuttle	Solar observatory	Similar to STS-95	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Nov. 6, 1998 Iridium 2, 83–86 66A–E Delta II*	Communications satellites	536 km 517 km 95 min 86°	
Nov. 22, 1998 Bonum 1 68A Delta II*	Communications satellite	Geosynchronous	Russian television satellite
Dec. 4, 1998 Space Shuttle *Endeavour* (STS-88) 69A Space Shuttle		401 km 388 km 92.4 min 51.6°	
Dec. 14, 1998 SAC-A 69B Space Shuttle	Carried a GPS receiver, magnetometer, and CCD camera	Similar to STS-88	Argentine minisatellite
Dec. 15, 1998 Mightysat 1 69C Space Shuttle	Advanced technology demonstrator experiments	Similar to STS-88	Minisatellite
Dec. 13, 1998 ISS Unity 69F Space Shuttle	U.S. module of the ISS	410 km 390 km 93 min 51.6°	
Dec. 6, 1998 SWAS 71A Pegasus-XL	Submillimeter Wave Astronomy Satellite	651 km 638 km 97.6 min 69.9°	
Dec. 11, 1998 MCO 73A Delta II	Mars Climate Orbiter	Interplanetary spacecraft	
Jan. 3, 1999 MPL 1A Delta II	Mars Polar Lander	Interplanetary spacecraft	
Jan. 27, 1999 Rocsat 1 2A Athena 1*	Earth resources monitoring satellite	601 km 589 km 96.6 min 35.0°	Taiwanese satellite

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Feb. 7, 1999 Stardust 3A Delta II	Spacecraft to collect "interstellar" dust using aerogel technology	Interplanetary spacecraft	
Feb. 16, 1999 JCSAT6 6A Atlas IIAS*	Communications satellite	Geosynchronous	Japanese satellite
Feb. 23, 1999 ARGOS 8A Delta II	Advanced Research Global Observation Satellite	842 km 822 km 102 min 98.7°	Technology demonstrator that should permit some observations
Feb. 23, 1999 Ørsted 8B Delta II	Ionospheric science spacecraft	857 km 644 km 100 min 96.5°	Danish satellite
Feb. 23, 1999 Sunsat 8C Delta II	Research and education satellite	857 km 644 km 100 min 96.5°	South African satellite
Mar. 5, 1999 WIRE 11A Pegasus-XL	Astronomical research spacecraft	593 km 539 km 96 min 97.5°	Payload became inoperable because of malfunction after launch.
Apr. 9, 1999 USA 142 (DSP19) 17A Titan IVB	Military (missile warning) spacecraft	Highly elliptical and useless orbit	Planned to be geosynchronous but now useless in orbit
Apr. 12, 1999 Eutelsat W3 18A Atlas IIAS*	Communications satellite	Geosynchronous	European consortium satellite
Apr. 15, 1999 Landsat 7 20A Delta II	Remote-sensing satellite	698 km 669 km 98.4 min 98.2°	
Apr. 30, 1999 USA 143 (Milstar 2) 23A Titan IVB	Military communications satellite	4,997 km 740 km 147 min	In useless low-Earth orbit

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
May 5, 1999 Orion 3 24A Delta III*	Communications satellite	1,317 km 422 km 102 min 29° (meant to be geosynchronous)	South Korean satellite is now in low, useless orbit.
May 18, 1999 TERRIERS 26A Pegasus-XL*	Space physics satellite	560 km 550 km 95.7 min 97.8°	Tomographic Experiment using Radiative Recombinative Ionospheric EUV and Radio Sources
May 18, 1999 MUBLCOM 26B Pegasus-XL*	Military communications satellite	790 km 775 km 100 min 97.8°	Multiple-path Beyond Line-of-sight Communications
May 22, 1999 USA 144 28A Titan IVB	Military spacecraft	Orbital parameters unavailable	
May 27, 1999 Space Shuttle *Discovery* (STS-96) 30A Space Shuttle	ISS supply mission	340 km 326 km 91.2 min 51.6°	
June 5, 1999 Starshine 30B Space Shuttle	Student passive reflector satellite	395 km 376 km 92 min 51.6°	
June 10, 1999 Globalstar 52, 49, 25, 47 31A–D Delta II*	Communications satellites	1,414 km 1,406 km 114 min 52°	
June 20, 1999 QuikSCAT 34A Titan II	Oceanographic satellite	815 km 281 km 95.6 min 98.7°	Microwave scatterometer instrument is follow-on to onboard Japanese Advanced Earth Observing Satellite (ADEOS).
June 24, 1999 FUSE 35A Delta II	Astronomical spacecraft	770 km 754 km 100 min 25°	Far Ultraviolet Spectroscopic Explorer
July 10, 1999 Globalstar 32, 20, 35, 51 37A–D Delta II*	Communications satellites	1,414 km 1,413 km 114 min 52°	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
July 23, 1999 Space Shuttle *Columbia* (STS-93) 40A Space Shuttle		280 km 260 km 90 min 28.5°	
July 23, 1999 Chandra X-ray Observatory 40B Space Shuttle	Astrophysics spacecraft	140,000 km 9,942 km 64 hours 28.5°	Formerly known as Advanced X-ray Astrophysics Facility (AXAF)
July 25, 1999 Globalstar 26, 28, 43, 48 41A–D Delta II*	Communications satellites	1,382 km 1,362 km 113 min 52°	
Aug. 17, 1999 Globalstar 24, 27, 53, 54 43A–D Delta II*	Communications satellites	1,386 km 1,362 km 113.3 min 52°	
Sep. 23, 1999 Echostar 5 50A Atlas IIAS-Centaur*	Communications satellite	Geosynchronous	
Sep. 24, 1999 Ikonos 2 51A Athena II*	Privately owned imaging satellite	682 km 678 km 98.4 min 98.2°	

* Commercial launch licensed as such by the Federal Aviation Administration.

APPENDIX C

U.S. and Russian Human Space Flights
1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Vostok 1	Apr. 12, 1961	Yury A. Gagarin	0:1:48	First human flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0:0:15	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	0:0:16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1:1:18	First flight exceeding 24 hrs.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0:4:55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0:4:56	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3:22:25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2:22:59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0:9:13	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1:10:20	First U.S. flight exceeding 24 hrs.
Vostok 5	June 14, 1963	Valery F. Bykovskiy	4:23:6	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2:22:50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1:0:17	First three-person crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1:2:2	First extravehicular activity (EVA), by Leonov, 10 min.
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0:4:53	First U.S. two-person flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	4:1:56	21-min. EVA (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7:22:55	Longest duration human flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13:18:35	Longest human flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1:1:51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0:10:41	First docking of two orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3:0:21	EVA; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2:22:47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sep. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2:23:17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km.).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3:22:35	Longest EVA to date (Aldrin, 5 hrs.).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1:2:37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10:20:9	First U.S. three-person mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3:22:51	Maneuvered near uncrewed Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6:3:1	First human orbit(s) of Moon; first human departure from Earth's sphere of influence; highest speed attained in human flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2:23:23	Soyuz 4 and 5 docked and transferred two cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3:0:56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10:1:1	Successfully simulated in Earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8:0:3	Successfully demonstrated complete system, including lunar module to 14,300 m from the lunar surface.
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	8:3:9	First human landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth and human deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valery N. Kubasov	4:22:42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	A. V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4:22:41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4:22:50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10:4:36	Second human lunar landing explored surface of Moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5:22:55	Mission aborted; explosion in service module. Ship circled Moon, with crew using Lunar Module as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17:16:59	Longest human space flight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9:0:2	Third human lunar landing. Mission demonstrated pinpoint landing capability and continued human exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1:23:46	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23:18:22	Docked with Salyut 1, and Soyuz 11 crew occupied space station for 22 days. Crew perished in final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12:7:12	Fourth human lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min., 12 sec. was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11:1:51	Fifth human lunar landing, with roving vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12:13:52	Sixth and final Apollo human lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28:0:50	Docked with Skylab 1 (launched uncrewed May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59:11:9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sep. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1:23:16	Checkout of improved Soyuz.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84:1:16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr I. Klimuk Valentin V. Lebedev	7:20:55	Astrophysical, biological, and Earth resources experiments.
Soyuz 14	July 3, 1974	Pavel R. Popovich Yury P. Artyukhin	15:17:30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennady V. Sarafanov Lev S. Demin	2:0:12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoly V. Filipchenko Nikolay N. Rukavishnikov	5:22:24	Test of Apollo-Soyuz Test Project (ASTP) configuration.
Soyuz 17	Jan. 10, 1975	Aleksey A. Gubarev Georgiy M. Grechko	29:13:20	Docked with Salyut 4 and occupied station.
Anomaly (Soyuz 18A)	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0:0:20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62:23:20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valery N. Kubasov	5:22:31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9:1:28	Docked with Soyuz 19 in joint (ASTP) experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48:1:32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sep. 15, 1976	Valery F. Bykovskiy Vladimir V. Aksenov	7:21:54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valery I. Rozhdestvenskiy	2:0:6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yury N. Glazkov	17:17:23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valery V. Ryumin	2:0:46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yury V. Romanenko Georgiy M. Grechko	37:10:6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days, 10 hrs.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64:22:53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days, 22 hrs., 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7:22:17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	9:15:23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days, 14 hrs., 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7:22:4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valery F. Bykovskiy Sigmund Jaehn	67:20:14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days, 20 hrs., 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valery V. Ryumin Nikolay N. Rukavishnikov	108:4:24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days, 36 min.
Soyuz 33	Apr. 10, 1979	Georgi I. Ivanov	1:23:1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	7:18:17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned without a crew.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valery V. Ryumin	55:1:29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 days, 20 hrs., 12 min.
Soyuz 36	May 26, 1980	Valery N. Kubasov Bertalan Farkas	65:20:54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days, 20 hrs., 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yury V. Malyshev Vladimir V. Aksenov	3:22:21	Docked with Salyut 6. First crewed flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79:15:17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days, 20 hrs., 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sep. 18, 1980	Yury V. Romanenko Arnaldo Tamayo Mendez	7:20:43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennady M. Strekalov	12:19:8	Docked with Salyut 6. First three-person flight in Soviet program since 1971.
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74:18:38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7:20:43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle *Columbia* (STS-1)	Apr .12, 1981	John W. Young Robert L. Crippen	2:6:21	First flight of Space Shuttle; tested spacecraft in orbit. First landing of airplane-like craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7:20:41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle *Columbia* (STS-2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2:6:13	Second flight of Space Shuttle; first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle *Columbia* (STS-3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8:4:49	Third flight of Space Shuttle; second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoly Berezovoy Valentin Lebedev	211:9:5	Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chrétien	7:21:51	Docked with Salyut 7. Chrétien first French cosmonaut to orbit.
Space Shuttle *Columbia* (STS-4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7:1:9	Fourth flight of Space Shuttle; first DoD payload; additional scientific payloads. Returned July 4. Completed testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7:21:52	Docked with Salyut 7. Savitskaya second woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle *Columbia* (STS-5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5:2:14	Fifth flight of Space Shuttle; first operational flight; launched two commercial satellites (SBS 3 and Anik C-3); first flight with four crew members. EVA test canceled when spacesuits malfunctioned.
Space Shuttle *Challenger* (STS-6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson F. Story Musgrave	5:0:24	Sixth flight of Space Shuttle; launched TDRS-1.

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U.S. and Russian Human Space Flights

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksandr Serebrov	2:0:18	Failed to achieve docking with Salyut 7 station.
Space Shuttle *Challenger* (STS-7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6:2:24	Seventh flight of Space Shuttle; launched two commercial satellites (Anik C-2 and Palapa B-1); also launched and retrieved SPAS 01; first flight with five crew members, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149:9:46	Docked with Salyut 7 station.
Space Shuttle *Challenger* (STS-8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6:1:9	Eighth flight of Space Shuttle; launched one commercial satellite (Insat 1-B); first flight of U.S. black astronaut.
Space Shuttle *Columbia* (STS-9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10:7:47	Ninth flight of Space Shuttle; first flight of Spacelab 1; first flight of six crew members, one of whom was West German; first non-U.S. astronaut to fly in U.S. space program (Merbold).
Space Shuttle *Challenger* (STS 41-B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7:23:16	Tenth flight of Space Shuttle; two communication satellites failed to achieve orbit; first use of Manned Maneuvering Unit in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovyev Oleg Atkov	62:22:43	Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-11.
Soyuz T-11	Apr. 3, 1984	Yury Malyshev Gennady Strekalov Rakesh Sharma	181:21:48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle *Challenger* (STS 41-C)	Apr. 6, 1984	Robert L. Crippen Francis R. Scobee Terry J. Hart George D. Nelson James D. van Hoften	6:23:41	Eleventh flight of Space Shuttle; deployment of Long-Duration Exposure Facility (LDEF-1) for later retrieval; Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11:19:14	Docked with Salyut 7 station. First female EVA.
Space Shuttle *Discovery* (STS 41-D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnik Charles D. Walker	6:0:56	Twelfth flight of Space Shuttle. First flight of U.S. nonastronaut.
Space Shuttle *Challenger* (STS 41-G)	Oct. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8:5:24	Thirteenth flight of Space Shuttle; first with seven crew members, including first flight of two U.S. women and one Canadian (Garneau).

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Discovery* (STS 51-A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7:23:45	Fourteenth flight of Space Shuttle; first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth.
Space Shuttle *Discovery* (STS 51-C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3:1:33	Fifteenth STS flight. Dedicated DoD mission.
Space Shuttle *Discovery* (STS 51-D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E. J. Garn	6:23:55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space (Garn).
Space Shuttle *Challenger* (STS 51-B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk van den Berg Taylor Wang	7:0:9	Seventeenth STS flight. Spacelab-3 in cargo bay of Shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112:3:12	Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.
Space Shuttle *Discovery* (STS 51-G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Prince Sultan Salman Al-Saud	7:1:39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-1. First U.S. flight with French and Saudi Arabian crew members.
Space Shuttle *Challenger* (STS 51-F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7:22:45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle *Discovery* (STS 51-I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7:2:18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sep. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64:21:52	Docked with Salyut 7 station. Viktor Savinykh, Aleksandr Volkov, and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle *Atlantis* (STS 51-J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert L. Stewart David C. Hilmers William A. Pailes	4:1:45	Twenty-first STS flight. Dedicated DoD mission.

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U.S. and Russian Human Space Flights
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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Challenger* (STS 61-A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford, Jr. Ernst Messerschmid Reinhard Furrer (FRG) Wubbo J. Ockels (ESA)	7:0:45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle *Atlantis* (STS 61-B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleave Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:22:54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut (Neri Vela).
Space Shuttle *Columbia* (STS 61-C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden Jr. Franklin Chang-Díaz Steve A. Hawley George D. Nelson Roger Cenker Bill Nelson	6:2:4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space (Bill Nelson).
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125:1:1	Docked with *Mir* space station on May 5/6 transfened to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to *Mir*.
Soyuz TM-2	Feb. 5, 1987	Yury Romanenko Aleksandr Laveykin	174:3:26	Docked with *Mir* space station. Romanenko established long-distance stay in space record of 326 days.
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160:7:16	Docked with *Mir* space station. Aleksandr Aleksandrov remained in *Mir* 160 days, returned with Yury Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30, with Aleksandr Laveykin who experienced medical problems. Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoly Levchenko	180:5	Docked with *Mir* space station. Crew of Yury Romanenko, Aleksandr Aleksandrov, and Anatoly Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	June 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov	9:20:13	Docked with *Mir* space station; Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valery Polyakov Abdul Mohmand	8:19:27	Docked with *Mir* space station; Mohmand first Afghanistani in space. Crew returned Sept. 7, in Soyuz TM-5.
Space Shuttle *Discovery* (STS-26)	Sep. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS-3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chrétien	151:11	Docked with *Mir* space station. Soyuz TM-6 returned with Chrétien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valery Polyakov returned Apr. 27, 1989, in Soyuz TM-7.

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U.S. and Russian Human Space Flights
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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Atlantis* (STS-27)	Dec. 2, 1988	Robert "Hoot" Gibson Guy S. Gardner Richard M. Mullane Jerry L. Ross William M. Shepherd	4:9:6	Twenty-seventh STS flight. Dedicated DoD mission.
Space Shuttle *Discovery* (STS-29)	Mar. 13, 1989	Michael L. Coats John E. Blaha James P. Bagian James F. Buchli Robert C. Springer	4:23:39	Twenty-eighth STS flight. Launched TDRS-4.
Space Shuttle *Atlantis* (STS-30)	May 4, 1989	David M. Walker Ronald J. Grabe Norman E. Thagard Mary L. Cleave Mark C. Lee	4:0:57	Twenty-ninth STS flight. Venus orbiter Magellan launched.
Space Shuttle *Columbia* (STS-28)	Aug. 8, 1989	Brewster H. Shaw Richard N. Richards James C. Adamson David C. Leestma Mark N. Brown	5:1	Thirtieth STS flight. Dedicated DoD mission.
Soyuz TM-8	Sep. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166:6	Docked with *Mir* space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8, Feb. 9, 1990.
Space Shuttle *Atlantis* (STS-34)	Oct. 18, 1989	Donald E. Williams Michael J. McCulley Shannon W. Lucid Franklin R. Chang-Díaz Ellen S. Baker	4:23:39	Thirty-first STS flight. Launched Jupiter probe and orbiter Galileo.
Space Shuttle *Discovery* (STS-33)	Nov. 23, 1989	Frederick D. Gregory John E. Blaha Kathryn C. Thornton F. Story Musgrave Manley L. "Sonny" Carter	5:0:7	Thirty-second STS flight. Dedicated DoD mission.
Space Shuttle *Columbia* (STS-32)	Jan. 9, 1990	Daniel C. Brandenstein James D. Wetherbee Bonnie J. Dunbar Marsha S. Ivins G. David Low	10:21	Thirty-third STS flight. Launched Syncom IV-5 and retrieved LDEF.
Soyuz TM-9	Feb. 11, 1990	Anatoly Solovyov Aleksandr Balandin	178:22:19	Docked with *Mir* space station. Crew returned Aug. 9, 1990, in Soyuz TM-9.
Space Shuttle *Atlantis* (STS-36)	Feb. 28, 1990	John O. Creighton John H. Casper David C. Hilmers Richard H. Mullane Pierre J. Thuot	4:10:19	Thirty-fourth STS flight. Dedicated DoD mission.
Space Shuttle *Discovery* (STS-31)	Apr. 24, 1990	Loren J. Shriver Charles F. Bolden, Jr. Steven A. Hawley Bruce McCandless II Kathryn D. Sullivan	5:1:16	Thirty-fifth STS flight. Launched Hubble Space Telescope (HST).
Soyuz TM-10	Aug. 1, 1990	Gennady Manakov Gennady Strekalov	130:20:36	Docked with *Mir* space station. Crew returned Dec. 10, 1990, with Toyohiro Akiyama, Japanese cosmonaut and journalist in space.

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U.S. and Russian Human Space Flights

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Challenger* (STS 61-A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford, Jr. Ernst Messerschmid Reinhard Furrer (FRG) Wubbo J. Ockels (ESA)	7:0:45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle *Atlantis* (STS 61-B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleave Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:22:54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut (Neri Vela).
Space Shuttle *Columbia* (STS 61-C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden Jr. Franklin Chang-Díaz Steve A. Hawley George D. Nelson Roger Cenker Bill Nelson	6:2:4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space (Bill Nelson).
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125:1:1	Docked with *Mir* space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to *Mir*.
Soyuz TM-2	Feb. 5, 1987	Yury Romanenko Aleksandr Laveykin	174:3:26	Docked with *Mir* space station. Romanenko established long-distance stay in space record of 326 days.
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160:7:16	Docked with *Mir* space station. Aleksandr Aleksandrov remained in *Mir* 160 days, returned with Yury Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30, with Aleksandr Laveykin who experienced medical problems. Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoly Levchenko	180:5	Docked with *Mir* space station. Crew of Yury Romanenko, Aleksandr Aleksandrov, and Anatoly Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	June 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov	9:20:13	Docked with *Mir* space station; Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valery Polyakov Abdul Mohmand	8:19:27	Docked with *Mir* space station; Mohmand first Afghanistani in space. Crew returned Sept. 7, in Soyuz TM-5.
Space Shuttle *Discovery* (STS-26)	Sep. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS-3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chrétien	151:11	Docked with *Mir* space station. Soyuz TM-6 returned with Chrétien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valery Polyakov returned Apr. 27, 1989, in Soyuz TM-7.

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U.S. and Russian Human Space Flights

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Discovery* (STS-41)	Oct. 6, 1990	Richard N. Richards Robert D. Cabana Bruce E. Melnick William M. Shepherd Thomas D. Akers	4:2:10	Thirty-sixth STS flight. Ulysses spacecraft to investigate interstellar space and the Sun.
Space Shuttle *Atlantis* (STS-38)	Nov. 15, 1990	Richard O. Covey Frank L. Culbertson, Jr. Charles "Sam" Gemar Robert C. Springer Carl J. Meade	4:21:55	Thirty-seventh STS flight. Dedicated DoD mission.
Space Shuttle *Columbia* (STS-35)	Dec. 2, 1990	Vance D. Brand Guy S. Gardner Jeffrey A. Hoffman John M. "Mike" Lounge Robert A. R. Parker	8:23:5	Thirty-eighth STS flight. Astro-1 in cargo bay.
Soyuz TM-11	Dec. 2, 1990	Viktor Afanasyev Musa Manarov Toyohiro Akiyama	175:01:52	Docked with *Mir* space station. Toyohiro Akiyama returned Dec. 10, 1990, with previous *Mir* crew of Gennady Manakov and Gennady Strekalov.
Space Shuttle *Atlantis* (STS-37)	Apr. 5, 1991	Steven R. Nagel Kenneth D. Cameron Linda Godwin Jerry L. Ross Jay Apt	6:0:32	Thirty-ninth STS flight. Launched Gamma Ray Observatory to measure celestial gamma-rays.
Space Shuttle *Discovery* (STS-39)	Apr. 28, 1991	Michael L. Coats Blaine Hammond, Jr. Gregory L. Harbaugh Donald R. McMonagle Guion S. Bluford, Jr. Lacy Veach Richard J. Hieb	8:7:22	Fortieth STS flight. Dedicated DoD mission.
Soyuz TM-12	May 18, 1991	Anatoly Artsebarskiy Sergei Krikalev Helen Sharman	144:15:22	Docked with *Mir* space station. Helen Sharman first from United Kingdom to fly in space. Crew of Viktor Afanasyev, Musa Manarov, and Helen Sharman returned May 20, 1991. Artsebarskiy and Krikalev remained on board *Mir*, with Artsebarskiy returning Oct. 10, 1991, and Krikalev doing so Mar. 25, 1992.
Space Shuttle *Columbia* (STS-40)	June 5, 1991	Bryan D. O'Connor Sidney M. Gutierrez James P. Bagian Tamara E. Jernigan M. Rhea Seddon Francis A. "Drew" Gaffney Millie Hughes-Fulford	9:2:15	Forty-first STS flight. Carried Spacelab Life Sciences (SLS-1) in cargo bay.
Space Shuttle *Atlantis* (STS-43)	Aug. 2, 1991	John E. Blaha Michael A. Baker Shannon W. Lucid G. David Low James C. Adamson	8:21:21	Forty-second STS flight. Launched fourth Tracking and Data Relay Satellite (TDRS-5).
Space Shuttle *Discovery* (STS-48)	Sep. 12, 1991	John Creighton Kenneth Reightler, Jr. Charles D. Gemar James F. Buchli Mark N. Brown	5:8:28	Forty-third STS flight. Launched Upper Atmosphere Research Satellite (UARS).

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-13	Oct. 2, 1991	Aleksandr Volkov Toktar Aubakirov (Kazakh Republic) Franz Viehboeck (Austria)	90:16:00	Docked with *Mir* space station. Crew returned Oct. 10, 1991, with Anatoly Artsebarskiy in the TM-12 spacecraft.
Space Shuttle *Atlantis* (STS-44)	Nov. 24, 1991	Frederick D. Gregory Tom Henricks Jim Voss F. Story Musgrave Mario Runco, Jr. Tom Hennen	6:22:51	Forty-fourth STS flight. Launched Defense Support Program (DSP) satellite.
Space Shuttle *Discovery* (STS-42)	Jan. 22, 1992	Ronald J. Grabe Stephen S. Oswald Norman E. Thagard David C. Hilmers William F. Readdy Roberta L. Bondar Ulf Merbold (ESA)	8:1:12	Forty-fifth STS flight. Carried International Microgravity Laboratory-1 in cargo bay.
Soyuz TM-14	Mar. 17, 1992	Aleksandr Viktorenko Aleksandr Kaleri Klaus-Dietrich Flade (Germany)	145:15:11	First manned CIS space mission. Docked with *Mir* space station Mar. 19. The TM-13 capsule with Flade, Aleksandr Volkov, and Sergei Krikalev returned to Earth Mar. 25. Krikalev had been in space 313 days. Viktorenko and Kaleri remained on the *Mir* space station.
Space Shuttle *Atlantis* (STS-45)	Mar. 24, 1992	Charles F. Bolden Brian Duffy Kathryn D. Sullivan David C. Leestma Michael Foale Dirk D. Frimout Byron K. Lichtenberg	9:0:10	Forty-sixth STS flight. Carried Atmospheric Laboratory for Applications and Science (ATLAS-1).
Space Shuttle *Endeavour* (STS-49)	May 7, 1992	Daniel C. Brandenstein Kevin P. Chilton Richard J. Hieb Bruce E. Melnick Pierre J. Thuot Kathryn C. Thornton Thomas D. Akers	8:16:17	Forty-seventh STS flight. Reboosted a crippled INTELSAT VI communications satellite.
Space Shuttle *Columbia* (STS-50)	June 25, 1992	Richard N. Richards Kenneth D. Bowersox Bonnie Dunbar Ellen Baker Carl Meade	13:19:30	Forty-eighth STS flight. Carried U.S. Microgravity Laboratory-1.
Soyuz TM-15	July 27, 1992	Anatoly Solovyov Sergei Avdeyev Michel Tognini (France)	189:17:43	Docked with *Mir* space station July 29. Tognini returned to Earth in TM-14 capsule with Aleksandr Viktorenko and Aleksandr Kaleri. Solovyov and Avdeyev spent over six months in the *Mir* orbital complex and returned to Earth in the descent vehicle of the TM-15 spacecraft on Feb. 1, 1993.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Atlantis* (STS-46)	Jul. 31, 1992	Loren J. Shriver Andrew M. Allen Claude Nicollier (ESA) Marsha S. Ivins Jeffrey A. Hoffman Franklin R. Chang-Díaz Franco Malerba (Italy)	7:23:16	Forty-ninth STS flight. Deployed Tethered Satellite System-1 and Eureka-1.
Space Shuttle *Endeavour* (STS-47)	Sep. 12, 1992	Robert L. Gibson Curtis L. Brown, Jr. Mark C. Lee Jerome Apt N. Jan Davis Mae C. Jemison Mamoru Mohri	7:22:30	Fiftieth STS flight. Carried Spacelab J. Jemison first African American woman to fly in space. Mohri first Japanese to fly on NASA spacecraft. Lee and Davis first married couple in space together.
Space Shuttle *Columbia* (STS-52)	Oct. 22, 1992	James D. Wetherbee Michael A. Baker William M. Shepherd Tamara E. Jernigan Charles L. Veach Steven G. MacLean	9:20:57	Fifty-first STS flight. Studied influence of gravity on basic fluid and solidification processes using U.S. Microgravity Payload-1 in an international mission. Deployed second Laser Geodynamics Satellite and Canadian Target Assembly.
Space Shuttle *Discovery* (STS-53)	Dec. 2, 1992	David M. Walker Robert D. Cabana Guion S. Bluford, Jr. James S. Voss Michael Richard Clifford	7:7:19	Fifty-second STS flight. Deployed the last major DoD classified payload planned for Shuttle (DoD 1) with ten different secondary payloads.
Space Shuttle *Endeavour* (STS-54)	Jan. 13, 1993	John H. Casper Donald R. McMonagle Gregory J. Harbaugh Mario Runco, Jr. Susan J. Helms	6:23:39	Fifty-third STS flight. Deployed Tracking and Data Relay Satellite-6. Operated Diffused X-ray Spectrometer Hitchhiker experiment to collect data on stars and galactic gases.
Soyuz TM-16	Jan. 24, 1993	Gennady Manakov Aleksandr Poleschuk	179:0:44	Docked with *Mir* space station Jan. 26. On July 22, 1993, the TM-16 descent cabin landed back on Earth with Manakov, Poleschuk, and French cosmonaut Jean-Pierre Haignere from Soyuz TM-17 on board.
Space Shuttle *Discovery* (STS-56)	Apr. 8, 1993	Kenneth D. Cameron Stephen S. Oswald C. Michael Foale Kenneth D. Cockerell Ellen Ochoa	9:6:9	Fifty-fourth STS flight. Completed second flight of Atmospheric Laboratory for Applications and Science and deployed Spartan-201.
Space Shuttle *Columbia* (STS-55)	Apr. 26, 1993	Steven R. Nagel Terence T. Henricks Jerry L. Ross Charles J. Precourt Bernard A. Harris, Jr. Ulrich Walter (Germany) Hans W. Schlegel (Germany)	9:23:39	Fifty-fifth STS flight. Completed second German microgravity research program in Spacelab D-2.
Space Shuttle *Endeavour* (STS-57)	June 21, 1993	Ronald J. Grabe Brian J. Duffy G. David Low Nancy J. Sherlock Peter J. K. Wisoff Janice E. Voss	9:23:46	Fifty-sixth STS flight. Carried Spacelab commercial payload module and retrieved European Retrievable Carrier in orbit since August 1992.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-17	July 1, 1993	Vasiliy Tsibliyev Aleksandr Serebrov Jean-Pierre Haignere	196:17:45	Docked with *Mir* space station July 3. Haignere returned to Earth with Soyuz TM-16. Serebrov and Tsibliyev landed in TM-17 spacecraft on Jan. 14, 1994.
Space Shuttle *Discovery* (STS-51)	Sep. 12, 1993	Frank L. Culbertson, Jr. William F. Readdy James H. Newman Daniel W. Bursch Carl E. Walz	9:20:11	Fifty-seventh STS flight. Deployed ACTS satellite to serve as testbed for new communications satellite technology and U.S./German ORFEUS-SPAS.
Space Shuttle *Columbia* (STS-58)	Oct. 18, 1993	John E. Blaha Richard A. Searfoss Shannon W. Lucid David A. Wolf William S. McArthur Martin J. Fettman	14:0:29	Fifty-eighth STS flight. Carried Spacelab Life Sciences-2 payload to determine the effects of microgravity on M. Rhea Seddon and animal subjects.
Space Shuttle *Endeavour* (STS-61)	Dec. 2, 1993	Richard O. Covey Kenneth D. Bowersox Tom Akers Jeffrey A. Hoffman Kathryn C. Thornton Claude Nicollier F. Story Musgrave	10:19:58	Fifty-ninth STS flight. Restored planned scientific capabilities and reliability of the Hubble Space Telescope.
Soyuz TM-18	Jan. 8, 1994	Viktor Afanasyev Yuri Usachev Valery Polyakov	182:0:27	Docked with *Mir* space station Jan. 10. Afanasyev and Usachev landed in the TM-18 spacecraft on July 9, 1994. Polyakov remained aboard *Mir* in the attempt to establish a new record for endurance in space.
Space Shuttle *Discovery* (STS-60)	Feb. 3, 1994	Charles F. Bolden, Jr. Kenneth S. Reightler, Jr. N. Jan Davis Ronald M. Sega Franklin R. Chang-Díaz Sergei K. Krikalev (Russia)	8:7:9	Sixtieth STS flight. Carried the Wake Shield Facility to generate new semi-conductor films for advanced electronics. Also carried SPACEHAB. Krikalev's presence signified a new era in cooperation in space between Russia and the United States.
Space Shuttle *Columbia* (STS-62)	Mar. 4, 1994	John H. Casper Andrew M. Allen Pierre J. Thuot Charles D. Gemar Marsha S. Ivins	13:23:17	Sixty-first STS flight. Carried U.S. Microgravity Payload-2 to conduct experiments in materials processing, biotechnology, and other areas.
Space Shuttle *Endeavour* (STS-59)	Apr. 9, 1994	Sidney M. Gutierrez Kevin P. Chilton Jerome Apt Michael R. Clifford Linda M. Godwin Thomas D. Jones	11:5:50	Sixty-second STS flight. Carried the Space Radar Laboratory-1 to gather data on the Earth and the effects humans have on its carbon, water, and energy cycles.
Soyuz TM-19	July 1, 1994	Yuri I. Malenchenko Talgat A. Musabayev	125:22:53	Docked with *Mir* space station July 3. Both Malenchenko and Musabayev returned to Earth with the Soyuz TM-19 spacecraft, landing in Kazakhstan on Nov. 4 together with Ulf Merbold of Germany, who went up aboard Soyuz TM-20 on Oct 3, 1994. Merbold gathered biological samples on the effects of weightlessness on the human body body in the first of two ESA missions to *Mir* to prepare for the International Space Station.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Columbia* (STS-65)	July 8, 1994	Robert D. Cabana James D. Halsell, Jr. Richard J. Hieb Carl E. Walz Leroy Chiao Donald A. Thomas Chiaki Naito-Mukai (Japan)	14:17:55	Sixty-third STS flight. Carried International Microgravity Laboratory-2 to conduct research into the behavior of materials and life in near weightlessness.
Space Shuttle *Discovery* (STS-64)	Sep. 9, 1994	Richard N. Richards L. Blaine Hammond, Jr. J. M. Linenger Susan J. Helms Carl J. Meade Mark C. Lee	10:22:50	Sixty-fourth STS flight. Used LIDAR In-Space Technology Experiment to perform atmospheric research. Included the first untethered spacewalk by astronauts in over 10 years.
Space Shuttle *Endeavour* (STS-68)	Sep. 30, 1994	Michael A. Baker Terrence W. Wilcutt Thomas D. Jones Steven L. Smith Daniel W. Bursch Peter J. K. Wisoff	11:5:36	Sixty-fifth STS flight. Used Space Radar Laboratory-2 to provide scientists with data to help distinguish human-induced environmental change from other natural forms of change.
Soyuz TM-20	Oct. 3, 1994	Aleksandr Viktorenko Yelena Kondakova Ulf Merbold (ESA)	*	Soyuz TM-19 returned to Earth on Nov. 4, 1994, with Yuri Malenchenko, Talgat Musabayev, and Ulf Merbold. Valeriy Polyakov remained aboard *Mir*.
Space Shuttle *Atlantis* (STS-66)	Nov. 3, 1994	Donald R. McMonagle Curtis L. Brown, Jr. Ellen Ochoa Joseph R. Tanner Jean-François Clervoy (ESA) Scott E. Parazynski	10:22:34	Sixty-sixth STS flight. Three main payloads: the third Atmospheric Laboratory for Applications and Science (ATLAS-3), the first Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite (CRISTA-SPAS-1), and the Shuttle Solar Backscatter Ultraviolet (SSBUV) spectrometer. Astronauts also conducted protein crystal growth experiments.
Space Shuttle *Discovery* (STS-63)	Feb. 3, 1995	James D. Wetherbee Eileen M. Collins Bernard A. Harris, Jr. C. Michael Foale Janice E. Voss Vladimir G. Titov (Russia)	8:6:28	Sixty-seventh STS flight. Primary objective: first close encounter in nearly 20 years between American and Russian spacecraft as a prelude to establishment of International Space Station. (Shuttle flew close by to *Mir*.) Main Payloads: Spacehab 3 experiments and Shuttle Pointed Autonomous Research Tool for Astronomy (Spartan) 204, Solid Surface Combustion Experiment (SSCE), and Air Force Maui Optical Site (AMOS) Calibration Test. Also launched very small Orbital Debris Radar Calibration Spheres (ODERACS).
Space Shuttle *Endeavour* (STS-67)	Mar. 2, 1995	Stephen S. Oswald William G. Gregory John M. Grunsfeld Wendy B. Lawrence Tamara E. Jernigan Ronald A. Parise Samuel T. Durrance	16:15:8	Sixty-eighth STS flight. Longest Shuttle mission to date. Primary payload was a trio of ultraviolet telescopes called Astro-2.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-21	Mar. 14, 1995	Vladimir Dezhurov Gennadi Strekalov Norman Thagard (U.S.)	*	Thagard was the first American astronaut to fly on a Russian rocket and to stay on the *Mir* space station. Soyuz TM-20 returned to Earth on Mar. 22, 1995, with Valeriy Polyakov, Alexsandr Viktorenko, and Yelena Kondakova. Polyakov set world record by remaining in space for 438 days.
Space Shuttle *Atlantis* (STS-71)	June 27, 1995	Robert L. Gibson Charles J. Precourt Ellen S. Baker Gregory Harbaugh Bonnie J. Dunbar	9:19:22	Sixty-ninth STS flight and one hundredth U.S. human space flight. Docked with *Mir* space station. Brought up Mir 19 crew (Anatoly Y. Solovyev and Nikolai M. Budarin). Returned to Earth with Mir 18 crew (Vladimir N. Dezhurov, Gennady M. Strekalov, and Norman Thagard). Thagard set an American record by remaining in space for 115 days.
Space Shuttle *Discovery* (STS-70)	July 13, 1995	Terence Henricks Kevin R. Kregel Nancy J. Currie Donald A. Thomas Mary Ellen Weber	8:22:20	Seventieth STS flight. Deployed Tracking and Data Relay Satellite (TDRS). Also conducted various biomedical experiments.
Soyuz TM-22	Sep. 3, 1995	Yuri Gidzenko Sergei Avdeev Thomas Reiter (ESA)	*	Soyuz TM-21 returned to Earth on Sep. 11, 1995, with Mir 19 crew (Anatoliy Solovyev and Nikolay Budarin).
Space Shuttle *Endeavour* (STS-69)	Sep. 7, 1995	David M. Walker Kenneth D. Cockrell James S. Voss James H. Newman Michael L. Gernhardt	10:20:28	Seventy-first STS flight. Deployed Wake Shield Facility (WSF-2) and Spartan 201-03.
Space Shuttle *Columbia* (STS-73)	Oct. 20, 1995	Kenneth D. Bowersox Kent V. Rominger Catherine G. Coleman Michael Lopez-Alegria Kathryn C. Thornton Fred W. Leslie Albert Sacco, Jr.	15:21:52	Seventy-second STS flight. Carried out microgravity experiments with the U.S. Microgravity Laboratory (USML-2) payload.
Space Shuttle *Atlantis* (STS-74)	Nov. 12, 1995	Kenneth D. Cameron James D. Halsell, Jr. Chris A. Hadfield (CSA) Jerry L. Ross William S. McArthur, Jr.	8:4:31	Seventy-third STS flight. Docked with *Mir* space station as part of International Space Station (ISS) Phase I efforts.
Space Shuttle *Endeavour* (STS-72)	Jan. 11, 1996	Brian Duffy Brent W. Jett, Jr. Leroy Chiao Winston E. Scott Koichi Wakata (Japan) Daniel T. Barry	8:22:1	Seventy-fourth STS flight. Deployed OAST Flyer. Retrieved previously launched Japanese Space Flyer Unit satellite. Crew performed spacewalks to build experience for ISS construction.
Soyuz TM-23	Feb. 21, 1996	Yuri Onufrienko Yuri Usachyou	*	Soyuz TM-22 returned to Earth on Feb. 29, 1996, with *Mir* 20 crew (Yuri Gidzenko, Sergei Avdeev, and Thomas Reiter).

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Columbia* (STS-75)	Feb. 22, 1996	Andrew M. Allen Scott J. Horowitz Jeffrey A. Hoffman Maurizio Cheli (ESA) Claude Nicollier (ESA) Franklin R. Chang-Díaz Umberto Guidoni (ESA)	13:16:14	Seventy-fifth STS flight. Deployed Tethered Satellite System, U.S. Microgravity Payload (USMP-3), and protein crystal growth experiments.
Space Shuttle *Atlantis* (STS-76)	Mar. 22, 1996	Kevin P. Chilton Richard A. Searfoss Linda M. Godwin Michael R. Clifford Ronald M. Sega Shannon W. Lucid**	9:5:16	Seventy-sixth STS flight. Docked with *Mir* space station and left astronaut Shannon Lucid aboard *Mir*. Also carried SPACEHAB module.
Space Shuttle *Endeavour* (STS-77)	May 19, 1996	John H. Casper Curtis L. Brown Andrew S. W. Thomas Daniel W. Bursch Mario Runco, Jr. Marc Garneau (CSA)	10:2:30	Seventy-seventh STS flight. Deployed Spartan/Inflatable Antenna Experiment, SPACEHAB, and PAMS-STU payloads.
Space Shuttle *Columbia* (STS-78)	June 20, 1996	Terrence T. Henricks Kevin Kregel Richard M. Linnehan Susan J. Helms Charles E. Brady, Jr. Jean-Jacques Favier (CSA) Robert B. Thirsk (ESA)	16:21:48	Seventy-eighth STS flight. Set Shuttle record for then-longest flight. Carried Life and Microgravity Sciences Spacelab.
Soyuz TM-24	Aug. 17, 1996	Claudie Andre-Deshays (ESA) Valery Korzun Alexander Kaleri	*	Soyuz TM-23 returned to Earth on Sep. 2, 1996, with Claudie Andre-Deshays, Yuri Onufrienko, and Yuri Usachev.
Space Shuttle *Atlantis* (STS-79)	Sep. 16, 1996	William F. Readdy Terrence W. Wilcutt Jerome Apt Thomas D. Akers Carl E. Walz John E. Blaha** Shannon W. Lucid***	10:3:19	Seventy-ninth STS flight. Docked with *Mir* space station. Picked up astronaut Shannon Lucid and dropped off astronaut John Blaha.
Space Shuttle *Columbia* (STS-80)	Nov. 19, 1996	Kenneth D. Cockrell Kent V. Rominger Tamara E. Jernigan Thomas David Jones F. Story Musgrave	17:15:53	Set record for longest Shuttle flight. At age 61, Musgrave became oldest person to fly in space. He also tied record for most space flights (six) by a single person. Crew successfully deployed ORFEUS-SPAS II ultraviolet observatory and Wake Shield Facility payloads.
Space Shuttle *Atlantis* (STS-81)	Jan. 12, 1997	Michael A. Baker Brent W. Jett Peter J.K. "Jeff" Wisoff John M. Grunsfeld Marsha S. Ivins Jerry M. Linenger** John E. Blaha***	10:4:56	Fifth Shuttle mission to *Mir*. Jerry Linenger replaced John Blaha as U.S. resident on *Mir*.

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U.S. and Russian Human Space Flights

1961–September 30, 1999

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-25	Feb. 10, 1997	Vasily Tsibliev Aleksandr Lazutkin Reinhold Ewald	*	Soyuz TM-24 returned to Earth on March 2, 1997, with Reinhold Ewald, Valery Korzun, and Aleksandr Kaleri.
Space Shuttle *Discovery* (STS-82)	Feb. 11, 1997	Kenneth D. Bowersox Scott J. Horowitz Joseph R. Tanner Steven A. Hawley Gregory J. Harbaugh Mark C. Lee Steven L. Smith	9:23:36	Crew successfully performed second servicing mission of the Hubble Space Telescope.
Space Shuttle *Columbia* (STS-83)	Apr. 4, 1997	James D. Halsell, Jr. Susan L. Still Janice Voss Michael L. Gernhardt Donald A. Thomas Roger K. Crouch Gregory T. Linteris	3:23:34	Crew deployed a Spacelab module configured as the first Microgravity Science Laboratory. Shuttle fuel cell malfunction necessitated an early termination of the mission.
Space Shuttle *Atlantis* (STS-84)	May 15, 1997	Charles J. Precourt Eileen Marie Collins Jean-François Clervoy Carlos I. Noriega Edward Tsang Lu Elena V. Kondakova Michael Foale** Jerry M. Linenger***	9:5:21	Sixth Shuttle mission to *Mir*. Michael Foale replaced Jerry Linenger on *Mir*.
Space Shuttle *Columbia* (STS-94)	July 1, 1997	James D. Halsell, Jr. Susan L. Still Janice Voss Michael L. Gernhardt Donald A. Thomas Roger K. Crouch Gregory T. Linteris	15:16:45	Reflight of STS-83 and the same payload, the Microgravity Science Laboratory. Mission proceeded successfully.
Soyuz TM-26	Aug. 5, 1997	Anatoly Solovyev Pavel Vinogradov	*	Soyuz TM-25 returned to Earth on August 14, 1997, with Vasily Tsibliev and Aleksandr Lazutkin.
Space Shuttle *Discovery* (STS-85)	Aug. 7, 1997	Curtis L. Brown, Jr. Kent V. Rominger N. Jan Davis Robert L. Curbeam, Jr. Stephen K. Robinson Bjarni V. Tryggvason	11:20:27	Crew successfully deployed two payloads: CRISTA-SPAS-2 on infrared radiation and an international Hitchhiker package of four experiments on ultraviolet radiation. The crew also successfully performed the Japanese Manipulator Flight Demonstration of a robotic arm.
Space Shuttle *Atlantis* (STS-86)	Sep. 25, 1997	James D. Wetherbee Michael J. Bloomfield Scott E. Parazynski Vladimir Titov Jean-Loup Chrétien Wendy B. Lawrence David A. Wolf** C. Michael Foale***	10:19:21	Seventh Shuttle docking with *Mir*. David Wolf replaced Michael Foale on *Mir*. Parazynski and Titov performed a spacewalk to retrieve four *Mir* Environmental Effects Payload experiments from the exterior of the docking module and left a solar array cover cap for possible future repair of the damaged *Spektr* module.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Columbia* (STS-87)	Nov. 19, 1997	Kevin R. Kregel Steven W. Lindsey Kalpana Chawla Winston E. Scott Takao Doi Leonid K. Kadenyuk	15:16:34	Payloads included USMP-4, Spartan 201-04 free-flyer, Collaborative Ukrainian Experiment (CUE) in space biology, and several other "hitchhiker" payloads.
Space Shuttle *Endeavour* (STS-89)	Jan. 22, 1998	Terrence W. Wilcutt Joe F. Edwards, Jr. James F. Reilly II Michael P. Anderson Bonnie J. Dunbar Salizhan S. Sharipov Andrew S. Thomas** David A. Wolf***	8:19:47	Eighth Shuttle docking mission to *Mir*. Andrew Thomas replaced David Wolf on *Mir*. Shuttle payloads included SPACEHAB double module of science experiments.
Soyuz TM-27	Jan. 29, 1998	Talgat Musabayev Nikolai Budarin Leopold Eyharts	*	Soyuz TM-26 left *Mir* and returned to Earth on February 19 with Anatoly Solovyev, Pavel Vinogradov, and Leopold Eyharts.
Space Shuttle *Columbia* (STS-90)	Apr. 17, 1998	Richard A. Searfoss Scott D. Altman Richard M. Linnehan Kathryn P. Hire Dafydd Rhys Williams Jay Clark Buckey, Jr. James A. Pawelczyk	15:21:50	Carried Neurolab module for microgravity research in the human nervous system. Secondary goals included measurement of Shuttle vibration forces, demonstration of the bioreactor system for cell growth, and three Get Away Special payloads.
Space Shuttle *Discovery* (STS-91)	June 2, 1998	Charles J. Precourt Dominic L. Pudwill Gorie Franklin R. Chang-Díaz Wendy B. Lawrence Janet Lynn Kavandi Valery V. Ryumin Andrew S. Thomas***	9:19:48	Last of nine docking missions with *Mir*, this one brought home Andrew Thomas. Payloads included DoE's Alpha Magnetic Spectrometer to study high-energy particles from deep space, four Get Away Specials, and two Space Experiment Modules.
Soyuz TM-28	Aug. 13, 1998	Gennady Padalka Sergei Avdeev Yuri Baturin	*	Docked to *Mir* using manual backup system because of prior failure of one of two automatic systems. Soyuz TM-27 left *Mir* returned to Earth with Talgat Musabayev, Nikolai Budarin, and Yuri Baturin.
Space Shuttle *Discovery* (STS-95)	Oct. 29, 1998	Curtis L. Brown, Jr. Steven W. Lindsey Scott E. Parazynski Stephen K. Robinson Pedro Duque (ESA) Chiaki Mukai (NASDA) John H. Glenn	8:21:44	Payloads included a SPACEHAB pressurized module, the Pansat communications amateur satellite, and the Spartan 201-05 solar observatory. Performed biomedical experiments on space flight and aging. Second flight of John Glenn.
Space Shuttle *Endeavour* (STS-88)	Dec. 4, 1998	Robert D. Cabana Frederick W. Sturckow James H. Newman Nancy J. Currie Jerry L. Ross Sergei K. Krikalev (RSA)	11:19:18	Payloads included Unity (Node 1), the first U.S. module of the ISS, as well as SAC-A and Mightysat 1.
Soyuz TM-29	Feb. 20, 1999	Viktor Afanasyev Jean-Pierre Haignere (ESA) Ivan Bella	*	Soyuz mission to *Mir*.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Discovery* (STS-96)	May 27, 1999	Kent V. Rominger Rick D. Husband Daniel T. Barry Valery I. Tokarev (RSA) Ellen Ochoa Julie Payette (CSA) Tamara E. Jernigan	9:19:13	ISS supply and repair mission; also launched the Starshine student passive reflector satellite.
Space Shuttle *Columbia* (STS-93)	July 23, 1999	Eileen M. Collins Jeffrey S. Ashby Michel Tognini (CNES) Steven A. Hawley Catherine G. Coleman	4:22:50	Deployed Chandra X-ray Observatory. Collins was first female commander of a Shuttle mission.

* *Mir* crew members stayed for various and overlapping lengths of time.
** Flew up on Space Shuttle; remained in space aboard Russian *Mir* space station.
*** Returned to Earth via Space Shuttle from Russian *Mir* space station.

APPENDIX D

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[b, c]	Max. Dia x Height (m)	Max. Payload (kg)[d] 185-km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Pegasus				6.71x15.5[h]	380 280[e]	—	210	1990
	1. Orion 50S	Solid	484.9	1.28x8.88				
	2. Orion 50	Solid	118.2	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Pegasus XL				6.71x16.93	460 350[e]	—	335	1994[g]
	1. Orion 50S-XL	Solid	743.3	1.28x10.29				
	2. Orion 50-XL	Solid	201.5	1.28x3.58				
	3. Orion 38	Solid	31.9	0.97x1.34				
Taurus				2.34x28.3	1,400 1,080[e]	255	1,020	Not scheduled
	0. Castor 120	Solid	1,687.7	2.34x11.86				
	1. Orion 50S	Solid	580.5	1.28x8.88				
	2. Orion 50	Solid	138.6	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Delta II (7920, 7925)				2.44x29.70	5,089 3,890[e]	1,842[i]	3,175	1990, Delta-7925 [1960, Delta]
	1. RS-270/A	LOX/RP-1	1,043.0 (SL)	3.05x38.1				
	Hercules GEM (9)	Solid	487.6 (SL)	1.01x12.95				
	2. AJ10-118K	N204/A-50	42.4	2.44x5.97				
	3. Star 48B[j]	Solid	66.4	1.25x2.04				
Atlas E				3.05x28.1	820[e] 1,860[e, k]	—	910[k]	1968, Atlas F [1958, Atlas LV-3A]
	1. Atlas: MA-3	LOX/RP-1	1,739.5 (SL)	3.05x21.3				
Atlas I				4.2x43.9	—	2,255	—	1990, I [1966, Atlas Centaur]
	1. Atlas: MA-5	LOX/RP-1	1,952.0 (SL)	3.05x22.16				
	2. Centaur I: RL10A-3-3A (2)	LOX/LH_2	73.4/ engine	3.05x9.14				
Atlas II				4.2x47.5	6,580 5,510[e]	2,810	4,300	1991, II [1966, Atlas Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-3-3A (2)	LOX/LH_2	73.4/engine	3.05x10.05				
Atlas IIA				4.2x47.5	6,828 6,170[e]	3,062	4,750	1992, Atlas IIA [1966, Atlas Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53/engine	3.05x10.05				
Atlas IIAS				4.2x47.5	8,640 7,300[e]	3,606	5,800	1993, IIAS [1966, Atlas Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	Castor IVA (4)[j]	Solid	433.6 (SL)	1.01X11.16				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53/engine	3.05x10.05				

APPENDIX D

(Continued)

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[b, c]	Max. Dia x Height (m)	Max. Payload (kg)[d] 185-km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Titan II				3.05x42.9	1,905[e]	—	—	1988, Titan II SLV [1964, Titan II Gemini]
	1. LR-87-AJ-5 (2)	N204/A-50	1,045.0	3.05x21.5				
	2. LR-91-AJ-5	N204/A-50	440.0	3.05x12.2				
Titan III				3.05x47.3	14,515	5,000[l]	—	1989, Titan III [1964, Titan IIIA]
	0. Titan III SRM (2) (5-1/2 segments)	Solid	6,210.0	3.11x27.6				
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5	3.05x24.0				
	2. LR91-AJ-11	N204/A-50	462.8	3.05x10.0				
Titan IV				3.05x62.2	17,700 14,110[e]	6,350[m]	—	1989, Titan IV
	0. Titan IV SRM (2) (7 segments)	Solid	7,000.0	3.11x34.1				
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5	3.05x26.4				
	2. LR91-AJ-11	N204/A-50	462.8	3.05x10.0				
Titan IV/				4.3x62.2	—	5,760[a]	—	1994, Titan IV Centaur
	0. Titan IV SRM (2) (7 segments)	Solid	7,000.0	3.11x34.1				
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5/engine	3.05x26.4				
	2. LR91-AJ-11(1)	N204/A-50	462.5	3.05x10.0				
	3. Centaur: RL-10A-3-3A	LOX/LH_2	73.4	4.3x9.0				
	4. SRMU (3 segments)		7690	3.3x34.3				
Space Shuttle[n]				23.79x56.14[h]	24,900[o]	5,900[p]	—	1981, *Columbia*
	1. SRB: Shuttle SRB (2)	Solid	11,790.0 (SL)	3.70x45.46				
	2. Orbiter/ET: SSME (3)	LOX/LH_2	1,668.7 (SL)	8.41x47.00 (ET) 23.79x37.24[h] (orbiter)				
	3. Orbiter/OMS: OMS engines (2)	N_2O_4/MMH	26.7	23.79x37.24[h]				
Delta III								
	1. RS-27A	LOX/RP-1	1,043.0 (SL)	4x39.1	8,292	3,810	6,768	1998[k]
	Alliant GEM (9)	Solid	608.8	1.16x14.7				
	2. RL-10B-2	LOX/LH_2	110	4x8.8				
	3. Star 48B	Solid	66.4	1.25x2.04				

APPENDIX D

(Continued)

U.S. Space Launch Vehicles

NOTES:

a. Propellant abbreviations used are as follows:
A-50 = Aerozine 50 (50% Monomethyl Hydrazine, 50% Unsymmetrical Dimethyl Hydrazine)
RP-1 = Rocket Propellant 1 (kerosene)
Solid = Solid Propellant (any type)
LH_2 = Liquid Hydrogen
LOX = Liquid Oxygen
MMH = Monomethyl Hydrazine
N_2O_4 = Nitrogen Tetroxide

b. Thrust at vacuum except where indicated at sea level (SL).

c. Thrust per engine. Multiply by number of engines for thrust per stage.

d. Inclination of 28.5° except where indicated.

e. Polar launch from Vandenberg AFB, CA.

f. First successful orbital launch [ditto of initial version].

g. First launch was a failure

h. Diameter dimension represents vehicle wing span.

i. Applies to Delta II-7925 version only.

j. Two Castor IVA motors ignited at liftoff. Two Castor IVA motors ignited at approximately 57 seconds into flight.

k. With TE-M-364-4 upper stage.

l. With Transfer Orbit Stage.

m. With appropriate upper stage

n. Space Shuttle Solid Rocket Boosters fire in parallel with the Space Shuttle Main Engines (SSME), which are mounted on the aft end of the Shuttle Orbiter Vehicle and burn fuel, and oxidizer from the External Tank. The boosters stage first, with SSME's continuing to fire. The External Tank stages next, just before the orbiter attains orbit. The Orbiter Maneuvering Subsystem is then used to maneuver or change the orbit of the Orbiter Vehicle.

o. 204-km circular orbit.

p. With Inertial Upper Stage or Transfer Orbit Stage.

NOTE: Data should not be used for detailed NASA mission planning without concurrence of the Director of Space Transportation System Support Programs.

APPENDIX E-1A

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY
(in millions of real-year dollars)

FY	NASA Total	NASA Space[b]	DoD	Other[c]	DoE	DoC	DoI	USDA	NSF[a]	DoT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43				0.1		1,066
1961	964	926	814	69	68				1		1,809
1962	1,825	1,797	1,298	200	148	51			1		3,295
1963	3,673	3,626	1,550	259	214	43			2		5,435
1964	5,100	5,016	1,599	216	210	3			3		6,831
1965	5,250	5,138	1,574	244	229	12			3		6,956
1966	5,175	5,065	1,689	217	187	27			3		6,971
1967	4,966	4,830	1,664	216	184	29			3		6,710
1968	4,587	4,430	1,922	177	145	28	0.2	1	3		6,529
1969	3,991	3,822	2,013	141	118	20	0.2	1	2		5,976
1970	3,746	3,547	1,678	115	103	8	1	1	2		5,340
1971	3,311	3,101	1,512	127	95	27	2	1	2		4,740
1972	3,307	3,071	1,407	97	55	31	6	2	3		4,575
1973	3,406	3,093	1,623	109	54	40	10	2	3		4,825
1974	3,037	2,759	1,766	116	42	60	9	3	2		4,641
1975	3,229	2,915	1,892	106	30	64	8	2	2		4,913
1976	3,550	3,225	1,983	111	23	72	10	4	2		5,319
TQ*	932	849	460	32	5	22	3	1	1		1,341
1977	3,818	3,440	2,412	131	22	91	10	6	2		5,983
1978	4,060	3,623	2,738	157	34	103	10	8	2		6,518
1979	4,596	4,030	3,036	177	59	98	10	8	2		7,243
1980	5,240	4,680	3,848	233	40	93	12	14	74		8,761
1981	5,518	4,992	4,828	233	41	87	12	16	77		10,053
1982	6,044	5,528	6,679	311	61	145	12	15	78		12,518
1983	6,875	6,328	9,019	325	39	178	5	20	83		15,672
1984	7,458	6,858	10,195	392	34	236	3	19	100		17,445
1985	7,573	6,925	12,768	580	34	423	2	15	106		20,273
1986	7,807	7,165	14,126	473	35	309	2	23	104		21,764
1987	10,923	9,809	16,287	462	48	278	8	19	108	1	26,558
1988	9,062	8,322	17,679	737	241	352	14	18	111	1	26,738
1989	10,969	10,097	17,906	560	97	301	17	21	116	3	28,563
1990	12,324	11,460	15,616	512	79	243	31	25	125	4	27,588
1991	14,016	13,046	14,181	697	251	251	29	26	131	4	27,924
1992	14,317	13,199	15,023	769	223	327	34	29	145	4	28,991
1993	14,310	13,064	14,106	698	165	324	33	25	139	4	27,868
1994	14,570	13,022	13,166	601	74	312	31	31	140	5	26,789
1995	13,854	12,543	10,644	629	60	352	31	32	141	6	23,816
1996	13,884	12,569	11,514	750	46	472	36	37	147	6	24,833
1997	13,709	12,457	11,727	728	35	448	42	39	152	6	24,912
1998	13,648	12,321	12,359	744	63	435	43	39	152	6	25,418
1999	13,653	12,459	13,203	937	102	575	59	37	158	6	26,599

* Transition Quarter

a. NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

b. Includes $2.1 billion for replacement of Space Shuttle *Challenger*.

c. "Other" column is the total of the non-NASA, non-DoD budget authority figures that appear in succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The "Total Space" column does not include the "NASA Total" column because it includes budget authority for aeronautics as well as in space. For the years 1989–1997, this "Other" column also includes small figures for the Environmental Protection Agency (EPA).

SOURCE: Office of Management and Budget

APPENDIX E-1B

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1999 DOLLARS
(adjusted for inflation)

FY	Inflation Factors	NASA Total	NASA Space	DoD	Other	DoE	DoC	DoI	USDA	NSF	DoT	Total Space
1959	4.7531	1,573	1,241	2,329	162	162						3,731
1960	4.6627	2,443	2,154	2,616	201	200				0.5		4,971
1961	4.6188	4,453	4,277	3,760	319	314				5		8,355
1962	4.5575	8,317	8,190	5,916	912	675	232			5		15,017
1963	4.5017	16,535	16,323	6,978	1,166	963	194			9		24,467
1964	4.4492	22,691	22,317	7,114	961	934	13			13		30,393
1965	4.3923	23,060	22,568	6,914	1,072	1,006	53			13		30,553
1966	4.3187	22,349	21,874	7,294	937	808	117			13		30,105
1967	4.1415	20,567	20,004	6,892	895	762	120			12		27,790
1968	4.0954	18,786	18,143	7,871	726	594	115	0.8	4	12		26,740
1969	3.9494	15,762	15,095	7,950	558	466	79	0.8	4	8		23,602
1970	3.7812	14,164	13,412	6,345	435	389	30	4	4	8		20,192
1971	3.5889	11,883	11,129	5,426	456	341	97	7	4	7		17,011
1972	3.4117	11,283	10,477	4,800	331	188	106	20	7	10		15,609
1973	3.2543	11,084	10,066	5,282	355	176	130	33	7	10		15,702
1974	3.1118	9,450	8,585	5,495	361	131	187	28	9	6		14,442
1975	2.9055	9,382	8,470	5,497	308	87	186	23	6	6		14,275
1976	2.6424	9,380	8,522	5,240	293	61	190	26	11	5		14,055
TQ	2.4647	2,297	2,093	1,134	79	12	54	7	2	2		3,305
1977	2.3843	9,103	8,202	5,751	312	52	217	24	14	5		14,265
1978	2.2863	9,283	8,283	6,260	359	78	235	23	18	5		14,902
1979	2.1409	9,840	8,628	6,500	379	126	210	21	17	4		15,507
1980	1.9861	10,407	9,295	7,643	463	79	185	24	28	147		17,400
1981	1.8288	10,092	9,130	8,830	426	75	159	22	29	141		18,385
1982	1.6683	10,083	9,222	11,142	519	102	242	20	25	130		20,884
1983	1.5616	10,736	9,882	14,084	508	61	278	8	31	130		24,473
1984	1.4945	11,146	10,249	15,236	586	51	353	4	28	149		26,071
1985	1.4406	10,909	9,976	18,393	836	49	609	3	22	153		29,204
1986	1.3953	10,893	9,997	19,710	660	49	431	3	32	145		30,367
1987	1.3628	14,886	13,368	22,196	630	65	379	11	26	147	1	36,193
1988	1.3277	12,031	11,049	23,472	978	320	467	19	24	147	1	35,499
1989	1.2862	14,108	12,987	23,031	720	125	387	22	27	149	4	36,738
1990	1.2383	15,261	14,191	19,337	634	98	301	38	31	155	5	34,162
1991	1.1930	16,721	15,563	16,917	831	299	299	35	31	156	5	33,312
1992	1.1498	16,461	15,176	17,273	884	256	376	39	33	167	5	33,333
1993	1.1245	16,091	14,690	15,862	785	186	364	37	28	156	4	31,336
1994	1.0967	15,979	14,281	14,439	659	81	342	34	34	154	5	29,379
1995	1.0720	14,852	13,446	11,411	674	64	377	33	34	151	6	25,531
1996	1.0498	14,576	13,195	12,088	787	48	496	38	39	154	6	26,071
1997	1.0300	14,120	12,831	12,079	750	36	461	43	40	157	6	25,569
1998	1.0128	13,822	12,478	12,517	754	64	441	44	39	154	6	25,743
1999	1.0000	13,653	12,459	13,203	937	102	575	59	37	158	6	26,599

SOURCE: Office of Management and Budget

APPENDIX E-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1997 actual	1998 actual	1999 est.	1997 actual	1998 actual	1999 est.
NASA	12,457	12,321	12,459	13,055	12,866	12,375
Defense	11,727	12,359	13,203	11,959	12,230	12,453
Energy	35	97	102	37	97	103
Commerce	448	435	575	336	326	431
Interior	42	42	59	42	42	59
Agriculture	39	39	37	39	39	37
Transportation	6	6	6	6	6	6
NSF	151	152	158	146	147	153

SOURCE: Office of Management and Budget.

APPENDIX E-3

Federal Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1997 actual	1998 actual	1999 est.	1997 actual	1998 actual	1999 est.
NASA[a]	1,252	1,327	1,194	1,302	1,339	1,218
Defense[b]	6,323	6,184	5,417	6,600	6,318	5,827
Transportation[c]	2,146	2,099	2,271	2,528	2,429	2,369

a. Research, Development, Construction of Facilities, Research and Program Management
b. Research, Development, Testing, and Evaluation of aircraft and related equipment.
c. Federal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development

SOURCE: Office of Management and Budget.

GLOSSARY

A

ACTS	Advanced Communications Technology Satellite
ADEOS	Advanced Earth Observing Satellite
ADS-B	Automated Dependent Surveillance-Broadcast
AEAP	Atmospheric Effects of Aviation Project
AGATE	Advanced General Aviation Technology Experiment
AMOS	Air Force Maui Optical Site
ARS	Agricultural Research Service (USDA)
AST	Advanced Subsonic Technology (Program)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTP	Apollo-Soyuz Test Project
ATLAS	Atmospheric Laboratory for Applications and Science
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AVOSS	Advanced Vortex Sensing System
AXAF	Advanced X-ray Astrophysics Facility (former name of Chandra X-ray Observatory)

B

BIA	Bureau of Indian Affairs (DoI)
Black hole	A completely collapsed, massive dead star whose gravitational field is so powerful that no radiation can escape from it; because of this property, its existence must be inferred rather than recorded from radiation emissions
BXA	Bureau of Export Administration (DoC)

C

CEOS	Committee on Earth Observation Satellites
CIS	Commonwealth of Independent States
CITEL	Commission on Inter-American Telecommunications
CME	Coronal Mass Ejections
CNES	Centre National d'Etudes Spatiales (France)
COPUOS	Committee on the Peaceful Uses of Outer Space (United Nations)
Corona	The outer atmosphere of the Sun, extending about a million miles above the surface
CORS	Continuously Operating Reference Station
Cosmic rays	Not forms of energy, such as x-rays or gamma rays, but particles of matter
COSPAR	Committee on Space Research
CrIS	Cross-track Infrared Sounder
CRISTA-SPAS	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite
CSC	Commercial Space Center
CSOC	Consolidated Space Operations Contract
CT	Computerized tomography
CUE	Collaborative Ukrainian Experiment

D

DAAC	Distributed Active Archive Center
DARWIN	Design Assessment of Reliability With Inspection
DMSP	Defense Meteorological Satellite Program—DoD's polar-orbiting weather satellite system
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DoS	Department of State
DoT	Department of Transportation
DSN	Deep Space Network
DSP	Defense Support Program

E

EELV	Evolved Expendable Launch Vehicle (program)
EHF	Extremely high frequency
El Niño	A warm inshore current annually flowing south along the coast of Ecuador around the end of December and extending about every 7 to 10 years down the coast of Peru
EOS	Earth Observing System—a series of satellites, part of NASA's Earth Science Enterprise, being designed for launch at the end of the 1990's to gather data on global change
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center (EPA)
ERAST	Environmental Research Aircraft and Sensor Technology (project)
EROS	Earth Resources Observation System (USGS)
ERS	European Remote-Sensing Satellite
ESE	Earth Science Enterprise
ESA	European Space Agency
ET	External Tank
ETM+	Enhanced Thematic Mapper-Plus (Landsat instrument)
EUV	Extreme ultraviolet
EVA	Extravehicular activity

F

FAA	Federal Aviation Administration
FACE	Free Air Carbon dioxide Enrichment
FAR	Federal Acquisition Regulation
FAS	Foreign Agricultural Service (USDA)
FCC	Federal Communications Commission
FGB	Functional Cargo Block (Russian acronym)
Fly-by-light	The use of light signals to connect the pilot's control devices with the aircraft control surfaces; or the use of light (fiber optic) control connections with no mechanical backup linkages and providing the pilot direct control of aircraft motion rather than control surface position
Fly-by-wire	The use of electrical signals to connect the pilot's control devices with the aircraft control surfaces; or the use of electrical control connections

	with no mechanical backup linkages and providing the pilot direct control of aircraft motion rather than control surface position
Free flight	A concept being developed by the FAA and the aviation community in which pilots could ultimately choose their own routes, speeds, and altitudes in flight, thus improving safety, while saving fuel, time, and natural resources.
FSA	Farm Service Agency (USDA)
FSS	Fixed Satellite Service
FWS	(U.S.) Fish and Wildlife Service (DoI)
FY	Fiscal year

G

Gamma rays	The shortest of electromagnetic radiations, emitted by some radioactive substances
GDIN	Global Disaster Information Network
Geo-stationary	Traveling around the Earth's equator at an altitude of at least 35,000 kilometers and at a speed matching that of the Earth's rotation, thereby maintaining a constant relation to points on the Earth
Geosyn-chronous	geostationary
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
GOIN	Global Observation Information Network
GPS	Global Positioning System

H

Heliosphere	The region of the Sun's influence, including the Sun and the interplanetary medium
HST	Hubble Space Telescope
Hypersonic	Faster than Mach 4; faster than "high speed"
Hyper-spectral	An instrument capability using many very narrow spectral frequency bands (300 or more), enabling a satellite-based passive sensor to discriminate specific features or phenomena on the body being observed (such as Earth)

I

ICM	Interim Control Module
IGEB	International GPS Executive Board
IGOS	Integrated Global Observing Strategy
IGS	International GPS Service for Geodynamics
INM	Integrated Noise Model
INMARSAT	International Mobile Satellite Organization
InSAR	Interferometric Synthetic Aperture Radar
INSAT	Indian Remote Sensing Satellite
Integrated modular avionics	Aircraft-unique avionics cabinet that replace multiple black boxes with shared common equipment and generic software
INTELSAT	International Telecommunications Satellite Organization
Inter-ferometry	The production and measurement of interference from two or more coherent wave trains emitted from the same source

Internet	An international computer network that began about 1970 as the NSF Net; very slowly it became a collection of more than 40,000 independently managed computer networks worldwide that have adopted common protocols to permit the exchange of electronic information
Ionosphere	That region of Earth's atmosphere so named because of the presence of ionized atoms in layers that reflect radio waves and short-wave transmissions
IPO	Integrated Program Office
ISO	International Organization for Standardization
ISS	International Space Station
ITA	International Trade Administration (DoC)
ITU	International Telecommunications Union

J

JEM	Japanese Experimental Module
JPL	Jet Propulsion Laboratory (NASA)

K

K-band	Radio frequencies in the 20-gigahertz range
Ka-band	Radio frequencies in the 30-gigahertz range
KSC	Kennedy Space Center
Ku-band	Radio frequencies in the 11–12-gigahertz range

L

Landsat	Land [remote sensing] Satellite—a series of satellites designed to collect information about Earth's natural resources
Laser	Light amplified by simulated emission of radiation—a device that produces an intense beam of light that may be strong enough to vaporize the hardest and most heat-resistant materials, first constructed in 1960
LDEF	Long-Duration Exposure Facility
LEO	Low-Earth Orbit—100 to 350 nautical miles above Earth
LH2	Liquid Hydrogen
LIDAR	Light Intersection Direction and Ranging
LOX	Liquid Oxygen
LVIS	Laser Vegetation Imaging Sensor

M

Mach	A relative number named after Austrian physicist Ernst Mach (1838–1916) and indicating speed with respect to that of sound in a given medium; in dry air at 32 degrees Fahrenheit and at sea level, for example, Mach 1=approximately 741 miles per hour (1,192 kilometers per hour)
Magnetosphere	The region of Earth's atmosphere in which ionized gas plays an important role in the atmospheric dynamics and where, consequently, the geomagnetic field also exerts an important influence; other magnetic planets, such as Jupiter, have magnetospheres that are similar in many respects to Earth's
MCC-H	Mission Control Center–Houston
MCC-M	Mission Control Center–Moscow
MCO	Mars Climate Orbiter

MHz	Megahertz
MilSatCom	Military Satellite Communications
MISR	Multi-angle Imaging Spectroradiometer
MMH	Monomethyl Hydrazine
MMS	Minerals Management Service (DoI)
MODIS	Moderate Resolution Imaging Spectrometer
MPL	Mars Polar Lander
MPLM	Multi-Purpose Logistics Module

N

NAPP	National Aerial Photography Program
NAS	National Airspace System (FAA)
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (of Japan)
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service (USDA)
NATO	North Atlantic Treaty Organization
NAWQA	National Water Quality Assessment
NCAP	National Civil Applications Program (USGS)
NDGPS	Nationwide Differential GPS
NDOP	National Digital Orthoquad Program
NESDIS	National Environmental Satellite, Data and Information Service (NOAA)
Neutron star	Any of a class of extremely dense, compact stars thought to be composed primarily of neutrons; see pulsar
NEXRAD	Next Generation Weather Radar
NGS	National Geodetic Survey
NGSO	Nongeostationary satellite
NIST	National Institute of Standards and Technology (DoC)
NOAA	National Oceanic and Atmospheric Administration (DoC); also the designation of that administration's Sun-synchronous satellites in polar orbit
Nominal	Functioning as designed
NOx	Oxides of nitrogen
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NPS	National Park Service (DoI)
NRA	NASA Research Announcement
NRCS	National Resources Conservation Service (USDA)
NRO	National Reconnaissance Office (DoD)
NSC	National Security Council
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration (DoC)—the Federal Government's radio spectrum manager, which coordinates the use of LEO satellite networks, such as those for Landsat, Navstar GPS, the Space Shuttle, and the Television and Infrared Operational Satellite (TIROS), with other countries of the world
NWRC	Northwest Watershed Research Center (ARS)

O

OAST	Office of Aerospace and Space Technology (former NASA office)
ODERACS	Orbital Debris Radar Calibration Spheres
OLMSA	Office of Life and Microgravity Sciences and Applications (NASA)
OMPS	Ozone Mapping and Profiler Suite
Order of magnitude	An amount equal to 10 times a given value; thus if some quantity was 10 times as great as another quantity, it would be an order of magnitude greater; if 100 times as great, it would be larger by two orders of magnitude
ORFEUS-SPAS	Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph-Shuttle Pallet Satellite
OSMRE	Office of Surface Mining Reclamation and Enforcement (DoI)
OSS	Office of Space Science (NASA)
OSTA	Office of Space and Terrestrial Applications (former NASA office)
OSTP	Office of Science and Technology Policy

P

PAMS-STU	Passive Aerodynamically Stabilized Magnetically Damped Satellite-Satellite Test Unit
PARCS	Primary Atomic Reference Clock in Space
Pathfinder	A program that focuses on the processing, reprocessing, maintaining, archiving, and distributing existing Earth science data sets to make them more useful to researchers; NASA, NOAA, and USGS are involved in specific Pathfinder efforts
PCB	Polychlorinated biphenyl
PEACESAT	Pan-Pacific Education and Communications Experiment by Satellite
PECAD	Production Estimates and Crop Assessment Division (FAS)
Photo-grammetry	The science or art of obtaining reliable measurements by means of photography
PMA	Pressurized Mating Adapter
POES	Polar-orbiting Operational Environmental Satellite (program)
PPS	Precise Positioning Service
PRA	Probabilistic risk assessment
Pulsar	A pulsating radio star, which is thought to be a rapidly spinning neutron star; the latter is formed when the core of a violently exploding star, called a supernova, collapses inward and becomes compressed together; pulsars emit extremely regular pulses of radio waves

Q

Quasar	A class of rare cosmic objects of extreme luminosity and strong radio emission; many investigators attribute their high-energy generation to gas spiraling at high velocity into a massive black hole
QuikSCAT	Quick Scatterometer

R

RADARSAT	Canadian Radar Satellite
Ramjet	A jet engine with no mechanical compressor, consisting of specially shaped tubes or ducts open at both ends, along with the air necessary for

	combustion being shoved into the duct and compressed by the forward motion of the engine
RFID	Radio Frequency Identification
RLV	Reusable launch vehicle
RPA	Remotely Piloted Aircraft
RSA	Russian Space Agency
RSML	Remote Sensing and Modeling Laboratory (ARS)

S

SAMRSS	Shafter Airborne Multispectral Remote Sensing System
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SBIRS	Space Based Infrared System
SBS	Satellite Business Systems
Scramjet	Supersonic-combustion ramjet
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SLS	Spacelab Life Sciences
SMA	Safety and Mission Assurance
SNOE	Student Nitric Oxide Experiment
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
Solar wind	A stream of particles accelerated by the heat of the solar corona (outer region of the Sun) to velocities great enough to permit them to escape from the Sun's gravitational field
SPACEHAB	Commercial module for housing Shuttle experiments
Spartan	Shuttle Pointed Autonomous Research Tool for Astronomy
SPOT	Satellite Pour l'Observation de la Terre (French satellite for the observation of Earth)
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSCC	Space Station Control Center
SSCE	Solid Surface Combustion Experiment
SSME	Space Shuttle Main Engine
SSM/I	Special Sensor Microwave Imager
SSRMS	Space Station Remote Manipulator System
SSTF	Space Station Training Facility
SSTI	Small Satellite Technology Initiative
START	Strategic Arms Reduction Treaty
STS	Space Transportation System
SWAS	Submillimeter Wave Astronomy Satellite

T

TA	Technology Administration (DoC)
TATP	Triacetone triperoxide (terrorist explosive)
TDRS	Tracking and Data Relay Satellite

TERRIERS	Tomographic Experiment using Radiative Recombinative Ionospheric EUV and Radio Sources
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TRACE	Transition Region and Coronal Explorer
TRACON	Terminal Radar Approach Control (system)
TRMM	Tropical Rainfall Measuring Mission

U

UARS	Upper Atmosphere Research Satellite
UHF	Ultrahigh frequency—any frequency between 300 and 3,000 megacycles per second
UNISPACE	United Nations Conference on the Exploration and Peaceful Uses of Outer Space
URET	User Request Evaluation Tool
U.S.	United States
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (DoI)
USML	U.S. Microgravity Laboratory
USMP	U.S. Microgravity Payload
USSR	Union of Soviet Socialist Republics
USWCL	U.S. Water Conservation Laboratory (ARS)

V

VCL	Vegetation Canopy Lidar
VHF	Very high frequency—any radio frequency between 30 and 300 megacycles per second
VLBA	Very Large Baseline Array
VLSA	Very Large Scale Aerial

W

WAAS	Wide Area Augmentation System
Wind shear	Variation of wind speed and wind direction with respect to a horizontal or vertical plane; powerful but invisible downdrafts called microbursts focus intense amounts of vertical energy in a narrow funnel that can force an aircraft to the ground nose first if the aircraft is caught underneath
WIRE	Wide-field Infrared Explorer
WRC	World Radiocommunication Conference
WSDDM	Weather Support to Deicing Decision Making
WSF	Wake Shield Facility

X-Y-Z

X-rays	Radiations of very short wavelengths, beyond the ultraviolet in the spectrum
XRSIM	X-ray simulation software

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